Studies on productivity of *Acacia tortilis* (Forsk.) Hayne based silvopastoral systems in Bundelkhand region

THESIS
Submitted to the Faculty of Science
Bundelkhand University, Jhansi

For the Degree of
Doctor of Philosophy
in
Botany

By
Gaurav Nigam

Division of Grassland and Silvopasture Management
Indian Grassland and Fodder Research Institute
JHANSI-284 003
2000

DEDICATED TO

MY BELOVED

PARENTS

भारतीय चरागाह एवं चारा अनुसंधान संस्थान
ग्वालियर मार्ग, झाँसी 284 003 (उ॰ प्र॰)
फोन : 91-517-444771 (कार्यालय), 440353 (निवास)
टेलीग्राम : घासानुसंधान, फैक्स : 91-517-440833

Indian Grassland and Fodder Research Institute
Gwalior Road, Jhansi 284 003 (U.P.) India
Telephone : 91-517-444771 (Off.) 440353 (Res.)
Gram : Ghasanusandhan, Fax : 91-517-440833
E-mail : npm@igfri.up.nic.in

एन॰ पी॰ मेलकानिया
शक (का॰)
N. P. Melkania
ctor (Actg.)

Dated: AR 2000

Forward

I have the pleasure of forwarding thesis entitled "Studies on productivity of *Acacia tortilis* (Forsk.) Hayne based silvopastoral systems in Bundelkhand region" submitted by Mr. Gaurav Nigam, Ph.D. scholar under supervision of Dr. M. M. Roy, Sr. Scientist, GSM Division, IGFRI, Jhansi.

2/3/2k

(N. P. Melkania)

INDIAN GRASSLAND AND FODDER RESEARCH INSTITUTE
Division of Grassland & Silvopasture Management
Gwalior Road, Jhansi - 284003 (U.P.) India
Phones : (0517) 442446, 444771 (O) 448023 (R)
Fax : 0517-440833, E mail: mmroy@mailcity.com

भाकृअनुप
ICAR

Dr. M. M. Roy
M. Sc. (Bot.), Ph. D.
Sr. Scientist

Date: 2 MAR 2000

CERTIFICATE

This is hereby certified that the thesis entitled "**Studies on productivity of *Acacia tortilis* (Forsk.) Hayne based silvopastoral systems in Bundelkhand region**" being submitted by **Mr. Gaurav Nigam**, for the award of degree of **Doctor of Philosophy** in **Botany**, contains original piece of research work. It is further certified that the thesis embodies the work of candidate himself.

The candidate had worked under my guidance and supervision for the period required under the University's Research Ordinance -7. The candidate has put more than required attendance at this institute during this period.

MMRoy
(M. M. Roy)

DECLARATION

I hereby declare that the thesis entitled **"Studies on productivity of *Acacia tortilis* (Forsk.) Hayne based silvopastoral systems in Bundelkhand region"** submitted by me for the award of the degree of Doctor of Philosophy in Botany, Faculty of Science, Bundelkhand University, Jhansi, is an original piece of work done by me and is not substantially the same as one which has already been submitted for degree or any other academic qualification at any other University or examining body in India or any other country to the best of my knowledge.

Dated: 2-3-2000

Gaurav Nigam

(Gaurav Nigam)

ACKNOWLEDGEMENT

It is a matter of great pleasure and pride for me to express my deep sense of gratitude and indebtedness to Dr. M. M. Roy, Senior Scientist, Division of Grassland and Silvopasture Management, Indian Grassland and Fodder Research Institute, Jhansi (U.P) for his inspiring and erudite guidance, constructive criticism and constant encouragement as well as extending all kinds of support in the conduct of the present investigation and preparation of manuscript.

I am highly grateful to Director, Indian Grassland and Fodder Research Institute Jhansi (U.P) for providing necessary facilities during the course of the experimentation.

I offer my esteemed thanks to Dr. Vinod Shankar, Head of Division, Division of Grassland and Silvopasture Management, Dr. R. C. Singh, Sr. Scientist (Agron.), Dr. B. K. Trivedi, Sr. Scientist (Eco. Botany), Dr. J. N. Gupta, Sr. Scientist, Dr. S. S. Parihar, Sr. Scientist (Eco. Botany), Dr. S. K. Gupta, Sr. Scientist (Eco. Botany), Dr. J. P. Singh, Sr. Scientist (Eco. Botany), Dr. S. K. Sharma, Scientist Sr. Scale (Hort.), Shri T. A. Khan, Scientist Sr. Scale (Statistics), Shri M. P. Rai, Expt. Scientist, Shri B. K. Chaubey, Expt. Scientist, Dr. S. K. Soam, Scientist (Eco. Botany), Dr. J.P. Singh, Scientist (Geog.), Dr. Sudhir Kumar, Scientist (Hort.), Dr. G. Suresh, Scientist (Agron.), Dr. Sunil Kumar, Scientist (Hort.), Shri Deepanker Saha, Scientist (Eco. Botany) for their help rendered during investigation and preparation of this manuscript.

I express my deep sence of gratitude to, Dr. R. K. Bhatt, Sr. Scientist (Eco. Botany), Dr. R. B. Yadav, Sr. Scientist (Soil Science), Shri Pradeep Behari, Scientist (Physics), Dr. Pradeep Saxena, Scientist (Plant Pathology), Shri N. C. Srivas, Sr. Tech. Officer, Dr. D. K. Singh, Tech. Assistant, and Shri N. K. Tripathi, Technical Assistant (Cartographer), Shri Rajendra Singh, Tech. Assistant, Shri Puran Singh, Tech. Assistant for their valuable suggestions and help during course of my investigation and thesis preparation.

Assistant rendered by Shri Tirath Raj Maurya, Sr. Tech. Assistant, and Shri Balloo in field work and Shri Shyam Lal and Khoobi Ram in laboratory is duly acknowledged.

I am specially grateful to Shri M. M. Rastogi, Technical Officer (Library), and Shri Vijay Kumar Paliwal, Sr. Clerk for their generous help at various stages.

The help, encouragement and all round support by my father Shri Sunder Lal Nigam, mother Smt. Shashi Bala Nigam and younger sister Km. Garima Nigam can't be expressed in words. I can't express my emotional feelings towards my family members for their support, persistent encouragement and providing all-round lofty idols in my life.

The financial support provided by the Indian Council of Agricultural Research, New Delhi for this investigation is also acknowledged.

Gaurav Nigam

Dated: 2-3-2000 (GAURAV NIGAM)

Jhansi

ACRONYMS/ABBREVIATIONS

A. D.	*Anno Domini*
ADF	Acid Detergent Fibre
AG	Aboveground
Av	Average
BG	Belowground
°C	Degree Celcius
Ca	Calcium
CAZRI	Central Arid Zone Research Institute
cd	Collor diameter
cm	Centimeter
CP	Crude Protein
Cv	Cultivar
dbh	Diameter at breast height
DM t/ha	Dry matter tonnes per hectare
FAO	Food and Agriculture Organisation
g	Gram
ha	Hectare
IGFRI	Indian Grassland and Fodder Research Institutre
K	Potassium
km	Kilometer
m	Meter
MAI	Mean annual increment
mm	Millimeter
MPTS	Multipurpose Trees and Shrubs
MS	Microsite
N	Nitrogen
NDF	Neutral Detergent Fibre
OC	Organic carbon
P	Phosphorus
PAR	Photosynthetically active radiation
pH	Potentiality of hydrogen ions
RH	Relative Humidity
t/ha/yr	Tonnes per hectare per year

LIST OF TABLES

Contd. on next page

Contd. on next page

LIST OF FIGURES

Contd. on next page

LIST OF PLATES

CONTENTS

CHAPTER 1

INTRODUCTION

INTRODUCTION

During the evolutionary history of man forests and grasslands have been important. There is a long history of development of grassland and co-existence of grazing animals as per their evolution. The grazing, trampling and other biotic activities of animals may have shaped the future of those early grazing lands, gradually both adapted to each other (Nagar, 1992).

The regularly managed pastures are virtually non-existent in the country. About 12 million ha of land in the country is officially recorded as pasture and grazing lands and this area is regularly decreasing due to pressure of providing more food and other agricultural products for the increasing human population. No effort has ever been made to assess the capacity of these lands and they were never put under regular scientific management. Even today there is no agency to manage the so-called pasture in the country (Lal, 1990).

India has more then 15 per cent of the total livestock population in the world, with only 2 per cent of world's geographical area. But it does not have specially identified and regularly managed pastures. There are 195 million cattle, 77 million buffalo, 144 million sheep and goat, 0.8 million horse and ponies, 1.0 million camels, 11 million pigs, 0.2 million mules, 1.0 million donkeys and in addition growing population of wildlife, which is likely to cross 495 million by 2000AD (Singh, 1988). In Bundelkhand region the livestock population is well over 9.43 million (Tyagi, 1997). Thus, India is the richest country of the world in animal population, but the average return per capita is very-very low as compared to those of other countries. One of the principal reasons of low livestock productivity in terms of milk, meat, wool etc. of our livestock is quite obvious and significant which can be explained in one word i.e. 'under feeding'. So, the principal reason assigned for low productivity of our livestock is inadequate production both in quality as well as quantity of fodder and other feeds including grazing facilities (Sahoo, 1996).

In India, grazing intensity ranges from 1.04 to 51.08 ACU/ha against the normal carrying capacity of 1 ACU/ha. The grazing intensity on semi-arid rangelands is estimated at 3.2 ACU/ha/yr, whereas a semi-arid rangeland of good range condition class has the carrying capacity of only 1 ACU/ ha/yr. In the arid rangelands, the grazing pressure ranges from 1 to 4 ACU ha/yr as against the carrying capacity of 0.2 to 0.5 ACU/ha/yr (Raheja, 1966; Shankar and Gupta 1993).

In Bundelkhand region grazing pressure on the rangelands is high, nearly 5 ACU per ha which is much higher than the state (0.67 ACU/ha) and national (2.5 ACU/ha) average (Singh and Singh, 1994). However the carrying capacity of a well-managed rangeland in this region does not exceed 1 ACU/ha (Shankar, 1988). So, the grazing resources are getting depleted because of heavy grazing pressure. The increased grazing pressure leads to the removal of perennial grass cover and succession of weeds and annuals (UNESCO, 1979).

The grazing demand for maintaining higher livestock productivity and economic returns from the animal is estimated to the order of 1253 million tonnes dry matter/year by 2000 AD. This requirement when split into dry and green works out to be to 949 and 1136 million tonnes, respectively. As against these, the present availability is 199, 215, 13 and 11 million tonnes of dry fodder, cultivated green fodder, natural herbage and concentrate which could be raised upto 357, 695 and 78 million tonnes of dry, green fodder and concentrate, respectively by 2000 AD (NWDB, 1990).

In Bundelkhand region the demand of fodder is 11.87 million tonnes against the supply level of 8.48 million tonnes. So the region has a deficit of 3.39 million tonnes of fodder (Singh and Singh, 1994; Tyagi, 1997).

Similarly, firewood crisis is the another main problem. India is highly dependent on the forests for firewood. Although the area under forest has been estimated to be 19.52 per cent of total geographical area but the productive and the effective forest area would be around 12-15 per cent only. Thus, in the

country, per capita forest area is only 0.18 ha as against the world average of 1.6 ha (Deb Roy, 1986).

Firewood forms the major source of energy in the rural sector. The Firewood Inquiry Committee appointed by the Planning Commission estimated that the quantity of firewood needed in the country was around 133 million tonnes. Of this 19 million tonnes came from forests and 30 million tonnes from private lands. The per capita consumption of firewood is estimated to vary from 0.15 to 0.6 tonnes in different states. The consumption of firewood has been estimated around 158 million tonnes in 2000 AD. The estimated yield of firewood from forest is 51 million tonnes and from private lands 26 million tonnes, leaving a deficit of 81 million tonnes in 2000 AD. Such a shortfall is a major cause of deforestation. The scarcity of firewood force people to burn about 60-80 million tonnes of dried dung which should have gone to field to increase agricultural production (Lal, 1990). The current requirement of firewood is around 280 million tonnes which is likely to rise to 350 million tonnes by 2000 AD in India (Mukherji, 1998). In Bundelkhand region the demand of firewood is around 2.50 million tonnes as against the supply level of 0.06 million tonnes. So the region has a deficit of 2.44 million tonnes of firewood (Singh and Singh, 1994).

The timber demand is also a major problem. The demand of timber is around 30 million m^3 out of which 8.3 million m^3 is needed for paper, pulp and panel products and 15.4 million m^3 for saw milling i.e. housing, packaging, furniture etc. The total timber requirement is estimated to grow to a level of 60 million m^3 by the year 2000 AD (Mukherji, 1998). In Bundelkhand region the demand of timber is 0.26 million m^3 against the supply level of 0.09 million m^3 only. So the region has a deficit of 0.17 million m^3 of timber (Singh and Singh, 1994).

Besides fodder, firewood, and timber requirements; in India, there is pressure to provide food to about 950 million people, which is likely to cross

1020 million in 2000 AD (Deb Roy, 1994 a). Similarly, in Bundelkhand region, there is pressure to provide food to over 12 million people (Tyagi, 1997).

In such a scenario, most of the arable lands are being utilized for grain and other cash crops. In order to meet the ever increasing grazing, fodder and timber demands forest and other grazing areas are under tremendous pressure, leading to overgrazing and deforestation.

Deforestation is identified as one of the major cause of land degradation, especially in the tropical countries. According to an estimate as much as 20 million ha of land that were once biologically productive are now degraded. The current rate of land degradation is estimated at 5-7 million ha per year and this rate may rise to 10 million ha per year by 2000 AD (Singh *et al.*, 1994). In Bundelkhand region the degraded land covers an area of 0.8 million ha i.e. 11.65 per cent of the total reporting area of Bundelkhand and this area is rising gradually (Tyagi, 1997).

The area under productive forest is shrinking at the rate of 1.5 million ha annually due to deforestation and overgrazing. These are mostly man made wastelands ascribed to the factors of sheet erosion, water logging, salinity and alkalinity, wind erosion, stream erosion, shifting cultivation, sand-dune movement etc. Land degradation further increases poverty, which in turn results in higher rate of degradation (Singh, 1988).

India, the seventh largest country of the world covers an area of 329 million ha but land use statistics are available only for 306 million ha. This include barren and unculturable land (28.2 million ha), the area under non-agricultural use (20.4 million ha), grazing land (11.9 million ha), culturable wasteland (25.29 million ha), current fallow land (15.40 million ha), cultivated area or net sown area (140.71 million ha) and the area under forests (64.2 million ha). Bundelkhand region covers a semi-arid area of 7.16 million ha in the central part of India. The land use include agricultural use (51.31 %), culturable

wasteland (17.28 %), forests (17.28 %) and permanent pastures, including grazing lands (13.32 %) (Bhumbla, 1992; Tyagi, 1997).

So, under the increasing demand of forage and fodder for our huge livestock and wildlife on the one hand and firewood and small timber for our daily needs on the other hand besides meeting the national target of 33.3 per cent area under tree and prevention of land degradation, there is no alternative but to adopt integrated approach of growing good fodder-cum fuel yielding trees along with grasses/grass-legume mixture in between the same land at the same time in some of the wastelands under integrated silvopastoral system (Deb Roy, 1990; Sahoo, 1996)

Under this system the inter space between the rows of trees are utilized for growing suitable grasses/grass-legume mixture instead of allowing weeds to grow in its place (King and Chandler, 1978). The whole concept is based on sound ecological principles. It is better to grow fuel-cum fodder trees in order to produce more leafy fodder having high digestible protein and minerals. It is of paramount importance during crucial lean period when the grasses are either grazed or become inedible (Baxi, 1985).

The advantages of silvopastoral system are both ecological and economical. Such system has potential in prevention of soil erosion and conservation of soil organic matter, moisture and plant nutrients. The shade provided by the grown up trees in the warm season prevent excessive evapotranspiration. Also, the trees serve as windbreaks and shelterbelts to reduce the wind velocity for the same purpose.

Tree/Shrubs can be used as barrier hedges and for improvement of soil fertility particularly through incorporation of nitrogen fixing trees. There are reports of increased soil fertility and better soil structure, reduction in soil erosion and surface run-off rate under tree cover. The water percolation and storage capacity increases under trees due to the deep penetrating roots, thus protecting against compaction and over heating. Also, the trees protect the area against

unfavourable climatic factors like desiccation and rapid moisture loss by improving microclimatic conditions (Olson, 1963; Baxi, 1985; Mishra and Nisanka, 1997). Thus, apart from improving the availability of fodder, fuel and minor timber these system help in environmental conservation (Singh *et al.*, 1994).

Silvopastoral system productivity keeps on changing because of micro-environmental variation, competition for water and nutrients. The allelopathy may play yet another role in determining the species dynamics of herbaceous flora and their production (Vitousek, 1984; Suresh and Vinay Rai, 1988; Ong *et al.*, 1991).

However, the information on such aspects is available only in pieces. There is lack of information on productivity and their interactions with microclimate and nutrient cycling aspect of man made silvopastoral agroecosystems. In silvopastoral system, the ecological and economic gains heavily depend on the exploitation of component interactions. In view of the Government of India's growing emphasis on taking up silvopastoral systems on a large scale, it becomes extremely important to understand such ecosystems from sustainability viewpoint.

In silvopastoral systems, microclimate amelioration involving soil moisture and soil temperature relations results primarily from the use of trees for shade, or as live supports, live fences or windbreaks and shelterbelts. The provision of shade causes a net effect of complex interactions, which extend far beyond the mere reduction of heat and light (Willey, 1975). Temperature, humidity and movement of air, as well as temperature and moisture of soil, directly affect photosynthesis, transpiration, and the energy balance of associated crops (Rosenberg *et al.*, 1983), the net effect of which may translate into increased yield.

Soil nutrients are affected by type of tree and understorey vegetation. Legumes increase soil nitrogen levels through symbiotic bacterial fixation of nitrogen. The livestock maintained on these systems, have important role in

recycling of nutrients through grazing besides the pasture composition. However, they may adversely affect some physical characteristics of soils (Borough, 1984). Leaves from the trees add organic matter to soil and change its physical and chemical properties. Nutrients are added to the soil by decomposition of the organic matter and mixing of the organic matter increases the water retaining capacity of soil. These have important implication in increasing infiltration and improving soil aeration.

The shade of tree also reduces air temperature, which gives more favourable environment to livestock. It is evident that shade and high quality fodder are important requirements for better productivity and higher-reproduction of animals in tropics, both can be provided through the inclusion of trees into agricultural systems (Ani *et al.*, 1985; Ismail, 1986).

Another potentially positive interaction in silvopastoral systems is related to weed. The effect of shade is more severe for light demanding plants than for shade tolerant plants. Thus, there could be avenues for suppressing some light demanding weeds under silvopastures.

It is therefore, important to find out how and why these systems function. Such a piece of information may be used to improve the productivity and sustainability of these systems, and also to design other system, which can survive and continue to be useful under changing environmental and social conditions.

In view of the above, the proposed study was planned to assess the system productivity of silvopastures based on *Acacia tortilis* - an important multipurpose and nitrogen fixing exotic tree with very high potential for afforestation programmes on extremely degraded lands having semi-rocky substratum (NAS, 1980; Shankar, 1988). It has been recommended as one of the most successful fast growing fodder-cum-fuel tree for the Bundelkhand tract (Pathak *et al.*, 1995).

In this study an attempt has been made to analyze *Acacia tortilis* based short/medium rotation silvopastoral system at the stage approaching maturity in ecosystem context. In order to achieve the objective the following studies were

undertaken on four microsites having grown up *Acacia tortilis* based silvopastoral system, including one microsite without trees (open situation) at Central Research Farm of Indian Grassland and Fodder Research Institute, Jhansi during 1997-1998.

(i) Monitoring microclimatic changes.

(ii) Botanical composition of understorey species and their growth pattern.

(iii) Phenology of tree component and its growth pattern.

(iv) Estimation of biomass in different plant parts of the pasture and tree components.

(v) Estimation of nutrient accumulation in different plant parts of pasture and tree components.

(vi) Quantification of litter production in different season and patterns of leaf litter decomposition.

(vii) Preparation of nutrient budgets.

(viii) Monitoring changes in soil physical parameters and fertility.

CHAPTER 2

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Silvopasture Research

Settled agriculture and animal husbandary have evolved through the forest. But still country is highly dependent on forests for various goods and services. Nomadic pastoralism is practised in several parts of country. Besides the needs of wood and other products from forest, the dependence of a large number of livestock on grazing is more in forest areas, village common property lands and wastelands (Pathak and Roy, 1994).

In India, silvopastoral research was practiced by ancient Indians. The practice of "Tungya" plantation in arid/semi-arid region are age old examples of silvopastures in India. Gradually the need was realised for developing ideal three dimensional ecosystems of tree/shrubs-grass-legume-animal under scientific management for optimum productivity and sustainability (Gill and Deb Roy, 1992).

In recent years, silvopasture has been developed as a science that promises to help farmers increase the productivity, profitability and sustainability of their land. In fact, it has evolved linking the survival with a system of diverse products through the experience of people. From a socioeconomic perspective, the silvopasture systems encompasses an immense social impact (FAO, 1978). Since 1970s there has been an increase in the recognition given to role of forests and trees in increasing agricultural productivity, human welfare, alleviation of energy problems and conservation of the environment. Initially, the goal of tree improvement for silvopasture was focused in increasing the effectiveness of land use for rural communities. In the modern context, however, attention has been paid to the efficient management of silvopasture, which includes processing and marketing too. The increasing emphasis placed on scientific experiments and cash returns, to a great extent, has helped to recognise value of the traditional systems which are related to management and household survival (Turbull, 1984).

In India, silvopasture research was initiated during the early sixties at the Central Arid Zone Research Institute (CAZRI), Jodhpur. This institute worked out the technologies for establishment of shelterbelts, stabilization of sand dunes and development of agri-silviculture systems. Later on comprehensive studies on such systems were taken up around 1970s at Indian Grassland and Fodder Research Institute (IGFRI), Jhansi. The studies included on designing and development of silvopastoral systems on degraded lands with special emphasis on fodder production on one hand and the conservation on the other hand. Gradually the other institutes *viz.*, Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Dehra Dun and Central Institute for Dryland Agriculture (CRIDA), Hyderabad initiated work on such systems to develop appropriate land use system in their respective regions. Besides these, an All India Coordinated Research Project on Agroforestry (AICRPAF) with 20 centres was initiated by ICAR during the year 1983. Silvopasture research in India was further strengthened during the seventh plan (1985-90) by adding 11 more centres to the AICRPAF and by creating a National Centre for Agforestry Research (NRCAF) at Jhansi during the year 1988. Now studies on various aspect of silvopastures are also undertaken by most of the State Agricultural Universities (SAUs) and some traditional universities as well.

Amelioration in Microclimate

Climate is one of the principal environmental factors which influence the interaction of biological organisms and impose many of the primary tolerance limits in the selection of the species capable of surviving in a given area. In the arid and semi-arid regions, for many ecological regions, forestry as a method of land use has gained acceptability. Of the various microclimatic parameters, knowledge of the incidence of radiation and its interception by the forest canopy, the temporal variations in air temperature, soil temperature, relative humidity, wind speed and interception of rainfall by the canopy structure are of great

importance in the silvopastoral and agroforestry systems as they decide the suitability of a particular crop or grass to be introduced into the forest ecosystem (Ramakrishna, 1984; Ong, 1991).

Studies carried out in a 7 year old *Acacia tortilis* plantation during the monsoon season at Jodhpur showed that during the morning hours air temperature beneath the tree canopy was lower by 0.1 °C to 0.7 °C than those recorded in the open, while during the afternoon period the temperatures underneath the tree canopy remained lower by as much as 0.6 °C to 2.0 °C than those recorded in the open (Ramakrishna and Sastri, 1977).

Ramakrishna and Sastri (1977) studied soil temperature in an agroforestry system involving gaur and *Acacia tortilis* (7 year old) at Jodhpur. In the *kharif* season, the mean daily maximum soil temperature beneath the tree cover was lower by as much as 10 °C to 16 °C in the top soil zone (0 - 5 cm) and 4 °C to 5 °C at 30 cm depth than those recorded in the open, which indicates a better soil thermal regime under the tree plantation.

Singh *et al.* (1980) assessed the effect of tree shade (full shade, partial shade and open area) on forage yield in a grassland planted with *Acacia catechu* and *Dalbergia sissoo* in north India. They noticed that forage yield was significantly higher in open than under partial shade or full shade. Average yield and clump diameter of grasses under partial shade of tree crown's edges were 86.7 and 38.0 per cent, respectively of that in the open patches, while under full shade of crowns the figures were 58.4 and 29.4 per cent, respectively.

Ramakrishna (1984) studied the pattern of rainfall interception in *Acacia tortilis* and *Holoptelia integrifolia* plantation at Jodhpur. The rainfall interception varied between 23 to 33 per cent and 14 to 19 per cent, respectively under moderate to heavy rainfall conditions. The rainfall pattern was attributed to the canopy shape and density of plant cover in case of *Acacia tortilis*.

Studies on microclimate variations around the tree cover by Ramakrishna (1984) revealed that under 13 year old *Acacia tortilis* based silvopastoral system,

the total incident radiation just beneath the tree canopy was only 14 to 30 per cent of that received in open areas. It was insufficient for good growth and productivity of pasture grasses like *Cenchrus ciliaris*.

Hazra and Patil (1986) studied light infiltration under four tree species *viz*., *Albizia lebbek*, *A. procera*, *Leucaena leucocephala* and *Acacia tortilis* at Jhansi. They found that light infiltration underneath the tree cover varied from 74 - 93 per cent of the PAR on open sites without trees. The tree cover also maintained higher air and leaf temperature when compared to open sites. Dry matter production by grasses under *Albizia lebbek*, *A. procera*, *Leucaena leucocephala* and *Acacia tortilis* was 665, 621, 565 and 608 gm/m^2, respectively. In open sites the production was 660 gm/m^2. Igbounugo *et al.* (1986) also reported similar increase in productivity of grasses with increase in light intensity.

Mishra and Bhatt (1990) studied interaction of infiltered light and canopy temperature on the productivity of grasses *viz.*, *Sehima nervosum* and *Heteropogon contortus* under the tree canopies of *Hardwickia binata*, *Leucaena leucocephala*, *Acacia tortilis*, *Albizia lebbek*, *Albizia amara*, *A. tortilis* and *H. binata* allowed 60 per cent and 55 per cent PAR infilteration of the total PAR whereas *L. leucocephala* infiltered least amount of PAR (33 %). Higher canopy air temperature difference (-6.8 °C) was recorded under *L. leucocephala.* About 98 per cent of dry matter yield of grasses were obtained under *H. binata* and *A. tortilis* canopy when compared with the dry matter yield in open field.

Amilioration in Soil Fertility

Yadav and Singh (1970) studied effect of forest plantation on an alkali soil near Aligarh. They observed a decrease in the pH value and soluble salt content and an increase in the amount of organic matter and nitrogen in the upper 15 cm layer under *Prosopis juliflora.* The soluble salts increased to some extent below 15 cm depth which was presumbly due to their downward translocation through leaching as a result of improved soil permeability.

The studies conducted by Aggarwal *et al.* (1975) on soil physico-chemical changes under 12 year old tree plantations in western Rajasthan showed that organic matter, total nitrogen and P_2O_5 was highest under *Prosopis cineraria* at 0-15 cm depth compared to the other trees such as *Acacia senegal*, *Albizia lebbek*, *Prosopis juliflora* and *Tecomella undulata* on bare site. This was also reflected in the higher number of herbaceous plant species (/m^2), mean plant density (/m^2) and mean above ground phytomass (g/m^2) under *P. cineraria* when compared to other species.

In a study on the amelioration role of mesquite (*Prosopis juliflora*) plantation, Virginia and Jarrel (1983) found that N (both nitrate and ammonical), organic carbon, $NaHCO_3$, extracable P and saturation extract K were significantly higher in the soil beneath mesquite. However, the differences in pH, osmotic potential, saturation per cent and sulphate content were not significant. They concluded that woody legumes fix nitrogen symbiotically and also add other nutrients in the surface beneath their canopies, which may be important in maintaining the long term productivity of desert ecosystem. Considerable increase in organic carbon and available nitrogen contents under mesquite plantations in highly alkaline soils in India has also been reported by Gill (1986).

Pathak and Gupta (1987) reported that organic matter addition through leaf litter in a two year old plantation of *Leucaena leucocephala* was in the range of 5.6 t/ha which improved soil tilth, cation exchange capacity, water holding capacity and bulk density besides reducing soil pH from alkaline to normal.

Chakrabotry and Chakraborty (1989) reported increase in organic carbon, nitrogen, potassium, electrical conductivity and water holding capacity under the canopy of *Acacia auriculiformis* when compared to that in the open.

Jha (1995) studied soil productivity of silvopastoral system with Napier grass in association with *Leucaena leucocephala* at Ranchi. Increase in organic carbon (0.4 to 0.49 %), available phosphorus (29 kg/ha to 46 kg/ha), available potassium (152 kg/ha to 179 kg/ha) and pH (5.8 to 6.5) of soil were reported.

The soil properties, in general, improves with tree cropping as compared to non-tree situation. Hazra (1990) found that field capacity, wilting point, organic carbon, cation exchange capacity and available N and P contents of soils were greatly improved, whereas bulk density, pH and EC values were appreciably decreased under *Albizia lebbek* plantation as compared to normal cropping. The canopy structure and also the type of tree species influenced the grass production underneath. The leguminous shrubs and trees had great influence in building up soil organic matter (0.32 to 0.91 %), available soil nitrogen (131 to 293 kg/ha), available phosphorus (6.2 to 18.5 kg/ha) and field capacity (11 to 15.8 %).

Isichel and Muoghalu (1992) evaluated the effect of tree canopy on soil fertility in Nigerian Savanna. Soils under tree canopies were found to have significantly greater levels of organic matter, calcium, magnesium, potassium, total exchangeable bases, CEC and pH then those in open grasslands. Trees of 7 m or more height had greater influence on soil properties than smaller trees.

In a study Vadiraj (1993) showed the influence of *Casuarina equisetifolia* plantation (1-8 year old) on the soil characteristics (especially on fertility) in Karnataka. It was reported that with increase in the age of the *Casuarina* plantation soil fertility increased. The significant increase in pH from 5.12 to 6.80, EC from 0.036 to 0.064 m-mhos/cm^2, organic carbon from 0.53 to 0.83 per cent, available P from 9 to 18.2 kg/ha, available K from 85 to 205 kg/ha, indicated that with the advance in the age of the plantation, there was a steady increase in the value.

The studies conducted on 20 year old tree plantation of *Acacia nilotica*, *Eucalyptus tereticornis*, *Prosopis juliflora*, *Terminalia arjuna* and *Albizia lebbek* in alkali soils at CSSRI, Karnal by Dagar *et al.* (1994) revealed that the decrease in soil pH was from 10.2 to 7.5. Simultaneously EC also decreased from 1.11 to 0.25. However, the organic carbon, P and K significantly increased from 0.22 per cent, 28 and 278 kg/ha to 0.85 per cent, 60-111 and 387-702 kg/ha, respectively.

Relative growth performance and soil enrichment potential of some nitrogen fixing trees (NFTS) were studied by Bhola (1995). The organic carbon, N, P, K, exchangeable Ca, Mg and Na as well as available Zn, Cu, Fe and Mn were appreciably higher and pH was lower under NFTS as compared to the open situation. Under each species with increase of peripheral distance (from tree trunk) the pH was more but all other parameters declined irrespective of the species.

Sharma *et al.* (1996) analyzed the soil profile under tree canopy and open field conditions. Better nutrient status in 0-20 cm and 20-60 cm soil depth was reported under tree canopy. The organic carbon, nitrogen and potassium (K_2O) in these profile depth was 0.15 per cent, 512 kg/ha, 309 kg/ha and 0.13 per cent, 522 kg/ha and 242 kg/ha, respectively under *Prosopis cineraria* canopy. In open situation, the value of organic carbon, nitrogen and potassium (K_2O) were 0.13 per cent, 449 kg/ha and 290 kg/ha and 0.13 per cent, 506 kg/ha and 295 kg/ha, respectively.

The studies conducted on 9 years old tree plantation of *Prosopis juliflora* on highly alkaline soils at Datia (Madhya Pradesh) by Gupta (1997) reported a decrease in soil pH from 9.8 to 8.3 and EC from 1.8 to 0.60 (dSm^{-1}). Similarly, the organic carbon, available nitrogen and available potassium increased significantly from 0.14 per cent, 132 and 186 kg/ha to 0.35 per cent, 210 and 214 kg/ha, respectively. However, there was little effect on available phosphorus from 6.64 to 6.83 kg/ha.

Pasture Yield

Singh and Puri (1975) evaluated productivity of *Acacia nilotica*, *Cenchrus ciliaris* and *Dichanthium annulatum* based silvopastoral system in the ravine areas around Agra. During the end of five years, *C. ciliaris* gave peak yield of 3.93 t DM/ha/yr in the 18 x 18 m tree spacing treatment while *D. annulatum* gave peak yield of 3.55 t DM /ha/yr in 9 x 9 m tree spacing treatment.

Paroda *et al.* (1977) studied compatibility of *Cenchrus ciliaris* with *Acacia tortilis, Colophospermum mopane* and *Leucaena leucocepala* at CAZRI, Jodhpur. They found highest survival in *A. tortilis* (98.5 %) followed by *L. leucocephala* (68.1 %) and *C. mopane* (26.7 %). The dry forage yield of grass ranged between 1.0 – 1.7 t DM/ha.

Grass production in 14 - 18 year old plantation of four desert trees was monitored by Ahuja *et al.* (1978) in arid situation. The peak forage yield was reported under *Prosopis cinerarea* (1.54 t DM/ha) and the least production was under *Acacia senegal* (0.69 t DM/ha). The increase in grass yield was attributed to increase in organic matter and increased availability of nutrients under *P. cinerarea.*

Deb Roy *et al.* (1978) studied the forage production of *Cenchrus ciliaris* and a mixture of *Chrysopogon fulvus* + *Sehima nervosum*, under different tree spacing of *Hardwickia binata* and *Albizia amara* from a typical degraded site in Bundelkhand. Forage production from the mixture of *C. fulvus* + *S. nervosum* (4.23 t DM/ha) was higher than that of *C. ciliaris* (3.74 t DM/ha).

Similarly, Roy *et al.* (1984) studied forage production of *Cenchrus ciliaris, Chrysopogon fulvus, Stylosanthes hamata* and *Macroptilium artopurpureum* in association with *Dichrostachys cinerea* on a highly calcareous wasteland site in this region. Peak forage yield was recorded in case of *Cenchrus ciliaris* (4.73 t DM/ha) followed by *Stylosanthes hamata* (3.92 t DM/ha), *Chrysopogon fulvus* (2.21 t DM/ha) and *Macroptilium artopurpureum* (1.57 t DM/ha).

Deb Roy (1986) reported higher pasture production from *Sehima nervosum* (7.8 t DM/ha) and *Chrysopogon fulvus* (7.4 t DM/ha) than for *Cenchrus ciliaris* (5.7 t DM/ha) in the third year of establishment in association with *Albizia lebbek* on a typical Bundelkhand wasteland with semi rocky substratum. At a similar such site the mixture of *Cenchrus ciliaris* and *Dolichos axillaris* gave peak forage production of 7.9 t DM/ha in association with *Albizia procera* whereas

Chrysopogon fulvus provided forage production of 6.0 t DM/ha in association with *Prosopis juliflora*.

Konwar *et al.* (1989) studied forage production from *Stylosanthes hamata* and *Cenchrus ciliaris* in association with *Leucaena leucocephala* planted in contour furrows spaced 7.5 m apart. The pasture production under *L. leucocephala* + *S. hamata* system was more productive (4.15 t DM/ha) than *L. leucocephala* + *C. ciliaris* (2.48 t DM/ha).

Arya (1995) studied mean dry grass production of 81.95 q/ha under *Poplar* plantation at 4 x 7 m spacing, whereas under *Eucalyptus* trees planted at 3x3m spacing yield was only 14.92 q/ha.

Deb Roy (1990) studied average forage production (5 years) of *Cenchrus ciliaris* and *Cenchrus setigerus* in association with *Acacia tortilis* and *Leucaena leucocephala*, *C. ciliaris* in association with *A. tortilis* gave an average forage production of 3.5 t DM/ha while in association with *L. leucocephala* it gave higher production (4.1 t DM/ha). In contrast, *C. setigerus* gave higher production (3.1 t DM/ha) in association with *A. tortilis* when compared to *L. leucocephala* (3.0 t DM/ha).

Yield from Trees

Roy and Deb Roy (1983) reported leaf fodder production of 10.2 kg/tree (4.0 t/ha) through one - third lopping of *Bauhinea purpurea* in alternate years. Lopping studies on two 6 - 7 year old *Albizia* species *viz.*, *Albizia lebbek* and *Albizia procera* grown in association with *Cenchrus ciliaris* + *Stylosanthes hamata* pasture revealed that the latter species gave not only higher leaf fodder production but also higher firewood production when compared to the former species. The mean green leaf fodder production of *A. procera* was 28.7 kg/tree (8.04 t/ha). The corresponding mean fuelwood production was 24.4 kg/tree (6.83 t/ha). Mean dry leaf fodder and fuelwood production was 15.6 kg/tree (4.37 t/ha) and 14.6 kg/tree (4.08 t/ha), respectively (Deb Roy, 1986).

Roy and Deb Roy (1986) reported that two - third lopping on an annual basis provided maximum and consistent fodder supplies from *Albizia amara* (Green: 10.95 t/ha, Dry: 5.59 t/ha). The corresponding green and dry firewood production were 17.84 and 10.2 t/ha, respectively. Biennial lopping on the other hand gave much lower production. Maximum green and dry leaf fodder and fuelwood production of 8.6, 4.7 kg/tree and 13.7, 8.2 kg/tree was observed in case of two - third lopping biennially.

Gill (1986) studied fuel and fodder production under agroforestry system on cultivated land by using *Sesbania grandifolia* as tree component at IGFRI, Jhansi. Maximum fuel produciton (3.75 t DM/ha) was registered with the pure *Sesbania* plantation treatment, closely followed by the *Sesbania* and *Nandi* grass treatment (3.73 t DM/ha).

Singh (1988 a) have observed that silvopastoral technology is successful in areas with less than 1000 mm rainfall, with a dry season for nine months. It has potential to produce 3.0-7.5 t/ha/yr fodder and 4.5-6.0 t/ha/yr firewood. In multi tiered system an additional grain yield of 0.6 t/ha/yr can also be obtained.

Swaminathan and Ravindran (1989) have studied the biomass production of four tree species for use in dry zone silvopasture system. It was found that *Dalbergia sissoo* had the highest ratio of forage (twigs and leaves) to the total biomass produced (20.30 %) followed by *Hardwickia binata* (18.77 %), *Leucaena leucocephala* (16.68 %) and *Albizia* (10.79 %). But in terms of the unit production of forage, *L. leucocephala* was found to have highest forage productivity (4.036 t/ha) followed by *Albizia* (0.588 t/ha), *Hardwickia* (0.480t/ha) and *Dalbergia* (0.358t/ha).

Rai *et al*. (1983) reported woody biomass production varying from 14.6 to 25.7 kg/tree in a medium to higher diameter class under silvopastoral system at 3.5 years for *Sesbania grandifolia* whereas for *S. sesban* it varied from 9.2 to 23.2 kg/tree grown at a spacing of 5 x 2.5 m.

Deb Roy and Gupta (1984) reported bole and branch wood production from 13 years old *Acacia tortilis* plantation under silvopastures at Jhansi. Maximum production of 117.6 kg/tree bole and 245.9 kg/tree branch (total wood production 363.6 kg/tree or 93.14 t/ha) was recorded in wider tree spacing in association with *Cenchrus ciliaris*. This was followed by 77.47 t/ha in narrower tree spacing in association with *Cenchrus setigerus*. Thus mean wood production was 57.50 t/ha (4.47 t/ha/yr). Muthana and Arora (1980) reported wood production from a 12 years old pure plantation of *A. tortilis* in arid region. The production was 53.6 t/ha in 3 x 3 m spacing and 39.2 t/ha in 6 x 6 m spacing.

Deb Roy (1988 a) reported woody biomass from a 9 years old *Albizia lebbek* plantation raised on a typical semi-arid wasteland of Bundelkhand. The mean biomass of 154.84 kg/tree was reported. The mean bole wood production was 77.86 kg/tree (varying from 49.6 to 96.2 kg/tree). Deb Roy and Gupta (1984) reported woody biomass production of 190 kg/tree from a 13 years old silvopastoral plantation of *Acacia tortilis*. Kalla *et al*. (1978), however, reported total wood production of 15.1 kg/tree from a 14 years old plantation of *Albizia lebbek* in arid Rajasthan.

Desale *et al*. (1990) reported that *Leucaena* in a agroforestry system, planted at 90 x 90 cm spacing and harvested for dry wood at the age of four years, produced 291.58 t/ha of dry wood whereas *Eucalyptus* planted at 60 x 60 cm spacing and harvested at the age of four years, produced 109.27 t/ha. As regards the coppice yield, *Eucalyptus* at the age of four years (spacing 30 x 30 cm) yielded maximum fuel (155.81 t/ha) when compared to the coppice yield of *Leucaena*, planted at 90 x 90 cm (123.20 t/ha).

Pathak *et al*. (1992) has studied tree productivity of a 15 year old *Albizia lebbek* plantation (density 400 trees/ha) silvopastoral system. From such a system 32.98 t/ha oven dry wood with an annual increment of 2.9 t/ha was reported. Parrotta (1989), however, reported wood production of 29.5 t/ha at 3 years from a

high density plantaiton of *A. lebbek* (10000 tree/ha) in Puerto Rico (1700 mm rainfall).

Gupta and Pathak (1994) studied the wood produciton of *Faidherbia albida* under silvopastoral system at 9 years of growth at Jhansi. The total biomass production was 41.8 t/ha of which 40.5 t/ha was wood. The production of bole was 23.1 t/ha while the branch was 17.4 t/ha.

Singh and Sengar (1994) reported the woody biomass production in an age series plantation of *Dalbergia sissoo* in Orai Forest Division, northern part of the Bundelkhand region in Uttar Pradesh. On area basis, maximum biomass was recorded in bole (155.04 t/ha) followed by branch (110.85 t/ha) from the 19 years old stand.

Raizada and Rao (1994) reported the biomass production and its distribution among different tree components, in an age series of *Eucalyptus* hybrid plantation in a red soil watershed at Chitradurga, Karnataka. The total above ground biomass production ranged from 5 t/ha (6 years) to 11.32 t/ha (14 years). The contribution of bole biomass to total above ground biomass decreased from 67 per cent (6 years) to 64 per cent (14 years). However, the contribution of branch biomass increased from 12 per cent (6 years) to 16 per cent (14 years).

Accumulation of Nutrients

The major recognized avenue for addition of organic matter to the soil, is through litterfall, that is through dead and falling leaves, twigs, branches, fruits, and so on (Brinson *et al.*, 1980). There are several studies on this process in tropical forests.

The biomass, productivity and nutrient cycling in a 24 year old *Dalbergia sissoo* plantation have been studied by Sharma *et al.* (1988). It was found that out of the total above ground biomass of 162 metric t/ha, the roots contributed 15.4 per cent. Maximum concentration of nitrogen was observed in leaf and minimum in the bole. The high concentration of Ca was found in bark and least in the bole.

As compared with the annual uptake of nutrients, 63 per cent N, 50 per cent P, 48 per cent K, 67 per cent Ca and 57 per cent of Mg were returned to the soil annually through litter fall.

Singh *et al.* (1993) reported biomass and nutrient (Ca, Mg, Na, K, P) distribution in the different components (leaves, branches, stems and roots) of six tree species in plantations of different ages (*Tectona grandis*, 30 yr old; *Dalbergia sissoo*, 19 yr old; *Emblica officinalis*, 9 yr old; *Eucalyptus* hybrid, 7 yr old; *Acacia auriculiformis*, 7 yr old; and *Hardwickia binata*, 19 yr old) on the *Bhata* soils of Raipur. Biomass was comparatively higher in *E. tereticornis* (26.74 kg/plant), *A. auriculiformis* (6.49 kg/plant), *H. binata* (36.45 kg/plant) and *P. emblica* (13.49 kg/plant) than in *T. grandis* (11.34 kg/plant) and *D. sissoo* (29.65 kg/plant). Nutrient content was higher in the leaves and lower in the roots of all species.

Singh (1994) have studied the pattern of biomass and nutrient accumulation in eight stands of *Cryptomeria japonica*, (7 - 40 years old) in the Darjeeling Hills. The above ground biomass varied from 5.5 to 158.0 t/ha. The highest concentration of most of the nutrients was found in the leaf. Nutrient concentrations of Ca (2.9 %) and N (2.3 %) were higher when compared to the nutrient concentration of P (0.022 %). Nutrient accumulation and biomass increased with age of stand but their proportion in aerial components of plants were greater in the young stand as compared to the mature stand. In early stages of stand development Ca was higher than N. The nutrient pool in standing crop biomass of the oldest stand was nearly 698 kg Ca, 422 kg Mg, 363 kg K, 67 kg Na, 117 kg N and 55 kg P per ha and their accumulation efficiency followed a similar pattern to that of biomass and nutrients with respect to stand age.

Negi *et al.* (1995) have reported the biomass and nutrient distribution of 10, 20 and 30 year old plantations of teak (*Tectona grandis*) in *Tarai* region of Uttar Pradesh. The total standing biomass of these stands increased with the increae in age/diameter (74.5 t/ha in 10 year stand to 164.1 t/ha in 30 year stand).

Maximum amount of N, P and Mg was accumulated in the bole while higher accumulation of Ca was observed in bark and roots. Harvesting of only utilisable biomass (148 t/ha) at the age of 30 years was found to deplete 247, 41, 170, 632 and 198 kg/ha of N, P, K, Ca and Mg, respectively.

Adu-Aning *et al.* (1995) reported the above ground biomass and nutrient content from 34 year old *Anogeisus leiocarpus*, 16 year old *Tectona grandis* (teak) and 10 year old *Azadirachta indica* (*neem*) grown in the Sudan savanna, Ghana. The mean tree biomass increased from 7.7 kg in neem through 8.6 kg in *T. grandis* to 29.0 kg in *A. leiocarpus* after 10, 16 and 34 years, respectively. A similar trend was recorded for the stand biomass as it was in the mean tree; *neem* with 400 trees/ha produced a stand biomass of 1391.2 kg/ha, teak 9529.8 kg/ha from 1625 trees/ha while *A. leiocarpus* produced the highest biomass of 45591.6 kg/ha from 1725 trees/ha. The concentrations and accumulations of N, P, K, Ca and Mg in the various above ground portions of the mean tree and stands of the *A. leiocarpus* were in the order of Ca>N>Mg>K>P, in teak; Ca>K>Mg>N>P, in *neem*; and Ca>K>N>Mg>P in *A. leiocarpus*. The concentrations of all the elements were highest in the leaves.

Tandon *et al.* (1996) have studied the biomass and nutrient accumulation in different age series of 4, 6, 8 and 10 years of *Eucalyptus* hybrid plantation at *Tarai* region of Uttar Pradesh. The total aboveground biomass at 4, 6, 8 and 10 years were 20, 35, 89 and 138 t/ha, respectively. The total amount of nutrients accumulated in the aboveground biomass ranged 78.4 kg/ha to 341 kg/ha in N; 1.9 kg/ha to 95 kg/ha in P; 36.8 kg/ha to 198.7 kg/ha in K; 69.9 kg/ha to 293.1 kg/ha in Ca and 25.4 kg/ha to 139.5 kg/ha in Mg from these plantations. Maximum amount of P, K and Mg was accumulated in the bole while maximum Ca was held up in bark at all ages. Accumulation of N was higher in leaf in younger plantations but as the stand reached maturity, higher accumulation of N was observed in the bole.

Nutrient Turnover

Silvopastoral system represents closed and efficient nutrient cycling systems, that they have high rates of turnover, and low rates of outputs or losses. Nutrient cycling in agroforestry/silvopastoral systems fall between these two extreme; more nutrients in the system are re-used by plants before being lost from the system. The major difference between agroforetry and other land use systems lies in the transfer or turnover of nutrients within the system from one component to the other, and the possibility of managing the system or its components to facilitate increased rates of turnover without affecting the overall productivity of the system (Golly *et al.*, 1978; Jordan, 1985).

The phenomena of litter fall, decomposition and nutrient release are universal in all kinds of biomes and ecosystems but their productivity, extent and pattern differ widely in different phytoclimatic belts and under the dominance of different plant species. Litter production and decomposition from the various ecosystems of the world have been studied by a number of workers (Bray and Gorham, 1964; Swift *et al.*, 1979; Vogt *et al.*, 1986).

Egunjobi (1974) studied the range of annual litter fall and nutrient return in an age group of 5-7 years of teak plantation in Nigeria. He found the annual litter fall in the range of 8.4 to 10.0 t/ha. Nutrient return on an annual basis was in the range of 78-101 kg/ha for nitrogen, 8.5-10.4 kg/ha for phosphorus and 188-210 kg/ha for calcium. Similarly, Lundgren (1978) has reported annual litterfall of 6.2 t/ha from 18 years old pine plantation in Tanzania. The annual nutrient return of nitrogen, phosphorus and calcium was of the order of 41.0, 2.0 and 48.0 kg/ha, respectively in such system.

Studies on litter production and nutrient return through litter fall carried out in *Eucalyptus tereticornis* plantation (5, 7 and 10 years old; density 1167, 1176 and 1133 trees/ha, respectively) have shown that these stands produced total litter in the range of 3377, 3801 and 6207 kg/ha, respectively. The amount of

various major nutrients returned to the soil through litter were found to be 30-59 kg/ha of nitrogen, 2-4 kg/ha of phosphorus, 15-31 kg/ha of calcium and 5-9 kg/ha of magnesium. The major proportion of all the nutrients was contributed by leaf litter followed by twig and bark litter (George, 1979).

Singh and Ambasht (1980) have studied the production and decomposition of litter in a poorly growing 13 years old *Tectona grandis* plantation at Chandraprabha Sanctuary, Chakia Hills, Varanasi. They have found an annual litter fall of 1.57 t/ha of which maximum litter production was in the winter (1.13 t/ha). Leaf accounted for most of the litter mass. Most of the litter remained on the ground during the summer and rapid decomposition took place in the rainy season (0.94 t/ha) followed by the summer season (0.35 t/ha). In one year period more than 90 per cent litter disappeared and the rest was carried to the next year as forest floor litter mass.

Singh *et al.* (1980) studied litter production and turnover of organic matter in the tropical dry deciduous scrub forest of *Zizyphus jujuba* in the Vindhyan hills of Varanasi. The amount of litter produced increased with the passage of time in the protected stands from 101.5 kg/ha/yr in 1975-76 to 129.9 kg/ha/yr in 1976-77 and 167.63 kg/ha/yr in 1977-78. The leaf litter accounted for 78, 70 and 68 per cent in the respective years, showing that there was a rise in the relative ratio of falling twigs and fruits in the *Zizyphus* stand.

Neil and Angelis (1981) observed little difference in litter fall between evergreen and deciduous species. Depending upon the number of trees per ha and age, litter fall varied from 0.5 to 6.5 t/ha/yr. On the dry weight basis leaf litter contained 0.5 to 1.5 per cent N, 0.05 to 0.15 per cent P, 0.25 to 0.75 per cent K, 0.25 to 1.0 per cent Ca and 0.1 to 0.2 per cent Mg. After decomposition a large proportion of these elements became available for plant growth.

Van den Beldt (1983) assessed litter fall of *Leucaena leucocephala* in Hawaii under stand densities ranging from 1000 to 4000 tree/ha. Average annual litter fall was about 8.54 t DM/ha. No significant effect of stand density on litter

production was observed. The studies on nutrient recycling showed that 100 kg N, 7 kg P, 16 kg K, 200 kg Ca and 12 kg S were recycled on a per ha per year basis through such litter.

Kushalappa (1987) has reported the annual nutrient return through litter on an unit area basis (kg/ha) from 6 years and 12 years old plantation of *Eucalyptus* hybrid. The maximum nutrient return was that of Ca and N in both the age series (38.9 kg/ha of Ca, and 32.8 kg/ha of N in 6 year old stands; 37.4 kg/ha of Ca and 38.5 kg/ha of N in 12 year old stands). The minimum return was of P which was 0.28 kg/ha and 0.33 kg/ha in 6 and 12 years old stands, respectively. Leaf litter contributed the maximum per cent of total nutrients returned (97 % of N, 89 % of P, 93 % of K and Ca and 92 % of Mg in 6 years old stands; 95 % of N, 85 % of P, 85 % of K and Ca and 87 % Mg in 12 years old stands).

In one study quantity of litter, its chemical composition, nutrient addition and changes in chemical constituents of soil were assessed under agroforestry system involving *Populus deltoides* and *Eucalyptus hybrid* tree with aromatic intercrops of *Cymbopogon martinii* and *C. flexuosus* in *Tarai* tract (Kumaon) of Uttar Pradesh. On an average dry litter production of *P. deltoides* was 5.0 kg/tree/year, whereas of *Eucalyptus* hybrid was 1.5 kg/tree/year. The litter of *P. deltoides* contained 1.3 times more N and 1.5 times more P and K than that of *Eucalyptus* hybrid. Addition of N, P and K through *Populus* litter was 36.6, 91.6 and 69.9 per cent more than *Eucalyptus* hybrid litter, respectively. Under these two canopies, soil organic carbon content increased from 33.3 to 83.3 per cent, available P increased from 3.4 to 32.8 per cent and available K increased from 5.8 to 24.3 per cent over control (no tree canopy) in 0-15 cm layer. In general, *P. deltoides* plantation was superior to the plantation of *Eucalyptus* hybrid in enriching the soil (Anonymous, 1988).

Chaubey *et al.* (1988) reported the comparative studies pertaining leaf litter production and nutrient return in teak plantations raised after clear felling of natural forests and in the adjoining natural forests in Madhya Pradesh. The leaf

litter production was found to be greater in teak plantation than in the adjoining natural forests. At Bijawar forest area, the total leaf litter output in teak plantation (20-23 years old) and in its adjoining natural forest was found to be 5.76 t/ha and 3.18 t/ha, respectively. Similarly, at Kalpi forest area, the teak plantation (20-23) produced 7.91 t/ha litter fall as against 3.60 t/ha litter production in adjoining natural forest. The per cent concentration of nutrients (N, P, K and Ca) was also higher in leaf litter of the plantation area when compared to the natural forest area. The quantities (kg/ha) of N, P, K and Ca returned to the soils *via* leaf litter in teak plantation was 71.93, 21.87, 26.47 and 143.3 kg/ha, whereas in adjoining natural forests it was 29.2, 8.26, 16.52 and 56.55 kg/ha, respectively.

Studies on the leaf litter production of dry deciduous forest ecosystem of Gir (Gujarat) indicated that Chhodavadi (teak dominated) alone contributed major portion to the total litter production (3.68 t/ha). Other species which contributed to the litter production at various sites were *Acacia catechu*, *Anogeissus latifolia*, *Butea monosperma* and *Diospyrus melanoxylom*. The total leaf litter production of Eastern Gir Forest was 10.17 t/ha, and the peak period of litter production was the month of February (Pandit *et al*., 1993).

Singh *et al*. (1993) observed the litter production and nutrient return in a tropical moist deciduous forest (a *Grewia tillifolia/Dalbergia* community) in Coimbatore Forest Division in Western Ghat of Tamil Nadu. The annual litter production was 14220 kg/ha of which leaf litter was 10754 kg/ha. On an annual basis 238 kg/ha of N, 9 kg/ha of P and 89 kg/ha of K were returned to the systems through litter fall.

Varshney and Garg (1996) estimated the litter production in *Albizia lebbek* stand in sub-tropical climatic conditions. The average annual litter production was found to be 799.1 g/m^2. Contribution of leaves to the total annual litter production was maximum (569.89 g/m^2 or 71.3 %). This was followed by reproductive structures (171.89 g/m^2 or 21.5 %) and twigs (57.5 g/m^2 or 7.2 %).

Tandon *et al.* (1996) reported the litter fall and nutrient return in four different aged *Eucalyptus* hybrid plantation stand at Dehra Dun. A total of 4565, 5242, 10236 and 9952 kg/ha of litter was produced annually at the ages 4, 6, 8 and 10 years, respectively. Out of total litter, leaf litter contributed between 73 to 82 per cent, thus maximum nutrients were returned to the soil through leaf litter. Maximum return was observed for nitrogen followed by calcium, potassium, magnesium and phosphorus.

Gupta (1997) studied the litter fall and nutrient return in a 9 years old plantation of *Prosopis juliflora* in alkaline soils at Datia, Madhya Pradesh. An average annual litter fall of 4.98 t/ha was recorded. The amount of nutrients *viz.*, nitrogen, phosphorus and potassium added to soil through litter on an annual basis were 112, 8 and 55 kg/ha, respectively.

In a field study involving 8-9 year old woodlots of nine fast growing multipurpose tree species in Kerala (India) the amount and release of nutrients through litter fall was studied by Jamaludheen and Mohan Kumar (1999). The average annual litter production was highest for *Acacia* (12.69 Mg/ha/yr) followed by *Paraserianthes* (9.17 Mg/ha/yr) and the lowest for *Pterocarpus* (3.42 Mg/ha/yr). Other MPTS showed a decreasing trend in the order: *Casuarina*> *A. heterophyllus*> *Emblica*> *Leucaena*> *Ailanthus*> *A. hirsutus*. Nutrient accretion through litter fall accounted for about 38-203 kg N/ha/yr, 0.8-6.0 kg P/ha/yr and 3.4-15.7 kg K/ha/yr, respectively.

CHAPTER 3

MATERIALS AND METHODS

MATERIALS AND METHODS

The Bundelkhand Region

Bundelkhand region comprises some part of Uttar Pradesh (24°11'-26°27' N latitude and 78°34' E longitude) and Madhya Pradesh (24° 40'-26° 50' N latitude and 76° 80'-80° 50'E longitude). The total geographical area of the region is 71,618 square kilometers. The human population is over 12 million. The livestock population is 9.43 million comprising of 5.36 million cattle, 1.64 million buffaloes, 1.82 million goats, 0.42 million sheep and 0.2 million other animals (Tyagi, 1997).

The topography of the region is characterized by its smooth flat lands and intermixed undulating areas of varied slope (Singh, 1971). The rainfall varies between 750 mm in north-west to about 1200 mm in south-west. About 90 per cent of the total precipitation is received between mid June to end September with occasional showers during winter months. The distribution of rainfall is often erratic and even wet months, July and August which receive about 70 per cent of the annual total, many a times experience long dry spells. May and June are the hottest months with maximum temperature of 43-46 °C. Minimum temperature of 3-4 °C is recorded during January. The area is termed as semi-arid with moisture index from -40 to –60 (Ghosh, 1991).

There are two major soil groups found in the region *viz.*, red and black (Singh, 1971). Red soils are coarse grained, upland soils and are found primarily in Jhansi and Lalitpur districts of UP. The black soils are heavy soils and are distributed in low leying areas of Jalaun, Hamirpur and Banda districts of UP. These major soil groups are further classified according to their texture and color into four distinct series namely *rakar* and *parwa* in red soil group and *kabar* and *mar* in black soil groups. About 56 per cent of the area of the region in under red soil group (Mannikar, 1981). In general, soils of this region are poor in nitrogen,

low to medium in phosphorus and medium to high in potash. Many a times different soils occur in a small area giving a typical mosaic appearance (Hazra, 1981). The region has natural and man made reservoirs besides river systems on which dams have been made at various places to provide irrigation through canals. Rivers like *Betwa*, *Ken*, *Pahauj* and *Dhassan* are important from the irrigation viewpoint (Singh and Singh, 1994).

Of the total geographical area, the net sown area in the region accounts for 43.2 per cent. About 29.8 per cent of net sown area are under irrigation. Well irrigation accounts for about 75 per cent of the total irrigated area of the region. The balance of 56.8 per cent of geographical area is occupied by forest, barren and uncultivated land, land put to non-agricultural use, cultivated wasteland, lands under miscellaneous tree crops and grass, permanent pastures and other grazing and fallow lands. The forest area accounts for about 16 per cent of the geographical area (Ghosh, 1991).

The natural vegetation of this region is tropical dry deciduous which shows its growth and species gradient from east to west and south to north (Champion and Seth, 1968). Selected areas in the forests are used for grazing by animals. Besides usual grazing areas, the forest department develops grass *birs* in areas not suitable for timber or firewood production and are situated within zones of high demand for fodder and grasses. After the harvest of mature grasses, these areas are open for stubble grazing within prescribed limit. The area under permanent pasture accounts for over 5 per cent of the geographical area. However, it has now decreased to a great extent due to transfer of such lands to landless persons. The area under miscellaneous tree crops and groves accounts for about 0.8 per cent of the georgraphical area. Such lands are used as a grazing ground as well as rest spot for the animals under scorching sun during summer and rainy season. Cultivated wastelands occupy over 8 per cent of the geographical area. Such lands are under continuous use for grazing. Fallow lands (current and old fallow) also constitute about 8 per cent of the geographical area.

These lands, left uncultivated due to various reasons, are used for growing grasses during rainy season. The area is either used for grazing or harvested grasses are conserved as hay for future use (Tyagi, 1988).

The Experimental Site

The study was carried out during January 1997 to December 1998 on a piece of degraded land at Central Research Farm of Indian Grassland and Fodder Research Institute, Jhansi (25° 27' N latitude and 78° 35'E longitude and about 275 m above sea level) (Fig. 1).

Present studies were undertaken to analyze silvopasture productivity of three different tree canopies (600, 400 and 100 trees/ha) and also of open situation (without any tree) in an ecosystem context.

Thus, for this study, The following four microsites were marked as under:

A. Microsite 1 (MS 1) - Open situation; no tree.
B. Microsite 2 (MS 2) - Sparse/light canopy situation with about 100 trees/ha.
C. Microsite 3 (MS 3) - Medium canopy situation with about 400 trees/ha.
D. Microsite 4 (MS 4) - Dense canopy situation with about 600 trees/ha.

Climate

The study area represent a typical, semi-arid monsoon type of climate characterized by dry summer, hot rainy season, warm autumn and cool winter. The study period received average annual rainfall about 945 mm. Approximately 90 per cent of the total rainfall was received between July to September. January was the rainless month and February received very little rainfall (< 1 mm). May was the hottest month with mean maximum temperature (41.3 °C) followed by June (39.1 °C). January was the coldest month with mean minimum temperature of (5.6 °C) followed by December (8.0 °C) (Fig. 2). Table 1 shows some meteorological parameters during the study period. It is evident that relative humidity almost followed the pattern of rainfall and temperature. May showed,

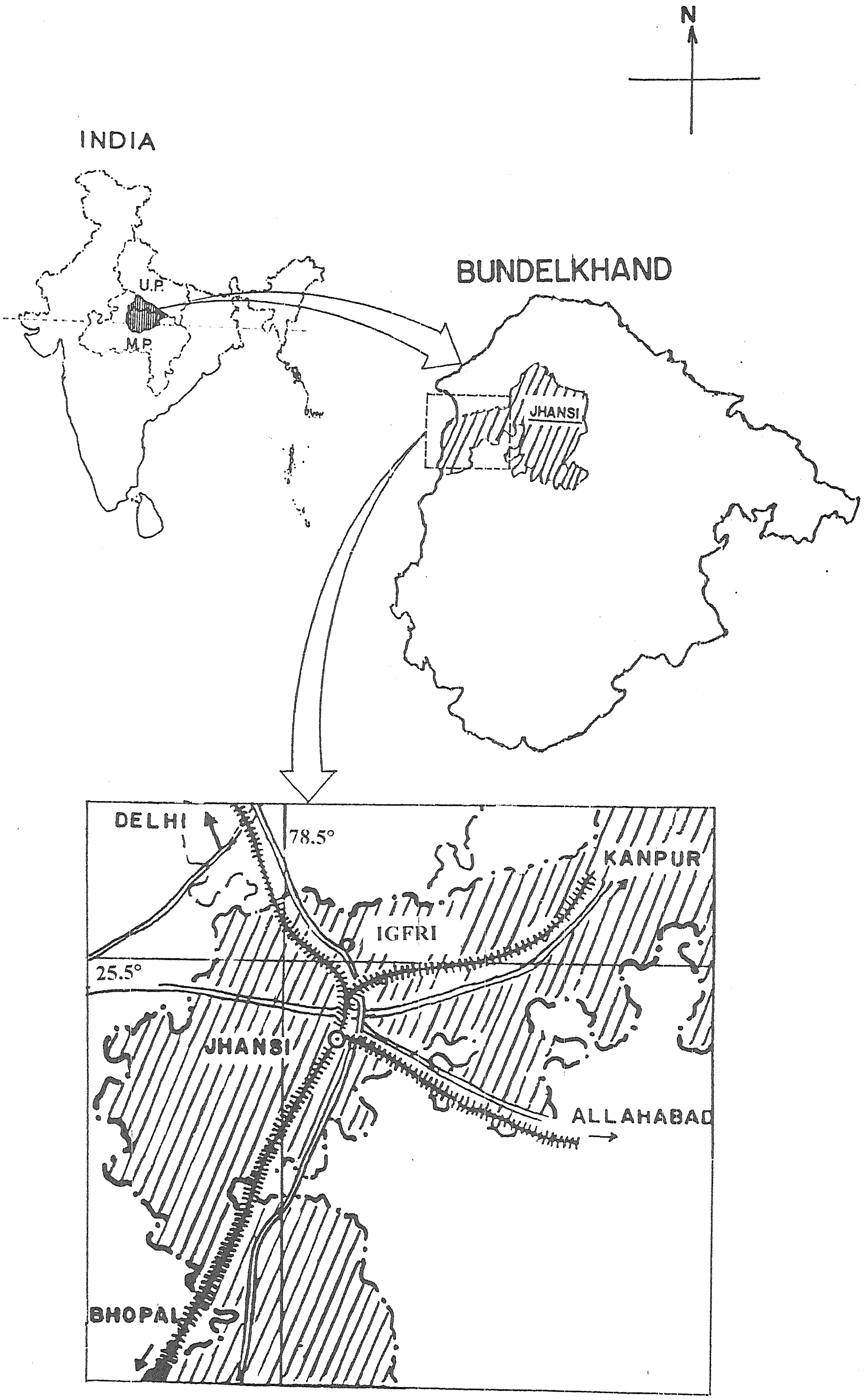
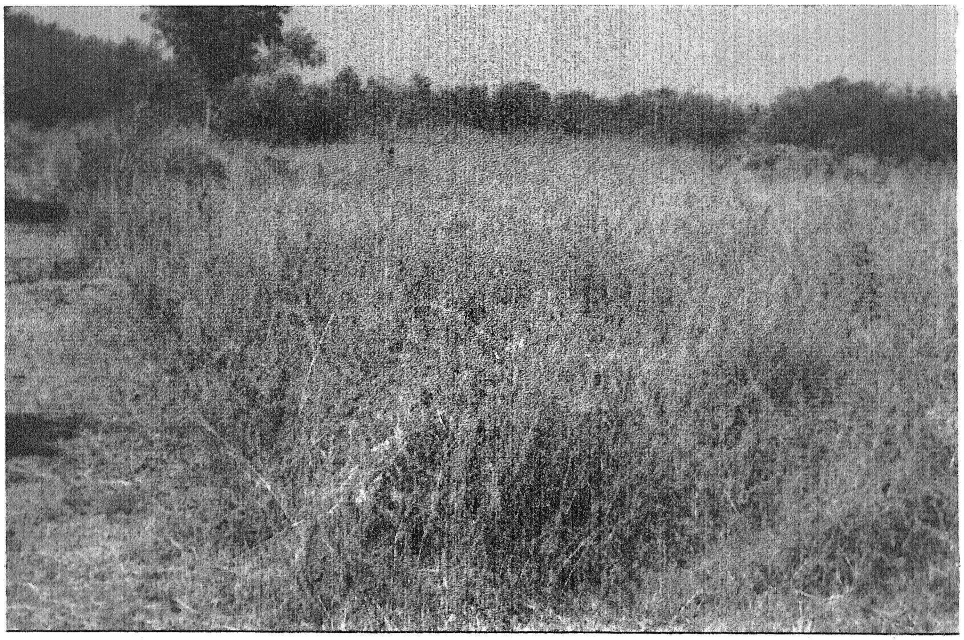


Fig. 1
Location of Bundelkhand region in India and the experimental site.

Plate 1

An outer view of the study site (*Acacia tortilis* stand in left)



A view of the only pasture situation (with out tree)

Table 1
Average meteorological parameters recorded at study site (1997-1998).

Months	Temp. (°C)		RH (%) Period		Rainfall (mm)	Rainy days (No.)	Wind velocity (km/hr)	Bright sunshine (hrs/day)	Evaporation (mm/day)
	Max.	Min.	Ist	IInd					
Jan.	22.0	5.6	95	41	000.0	0.0	1.1	7.8	2.0
Feb.	26.6	8.7	91	32	000.9	0.0	2.5	9.4	3.6
Mar.	30.6	13.4	88	30	011.6	1.5	3.8	8.7	4.8
Apr.	37.3	21.8	68	25	013.4	1.5	3.9	9.7	7.5
May	41.3	24.6	55	26	017.0	2.5	6.8	10.2	11.5
June	39.1	27.0	64	37	061.8	6.0	7.6	8.0	10.5
July	33.8	25.7	87	64	297.5	13.5	5.5	4.4	4.4
Aug.	31.9	24.9	93	73	281.1	15.0	3.6	4.0	3.2
Sept.	33.3	24.3	91	62	113.9	7.5	1.8	7.6	4.0
Oct.	31.8	17.1	91	52	054.1	2.5	1.4	8.0	3.2
Nov.	27.4	12.8	92	47	014.5	1.0	1.3	7.0	2.3
Dec.	22.1	8.0	93	66	079.6	1.5	1.3	2.7	1.5

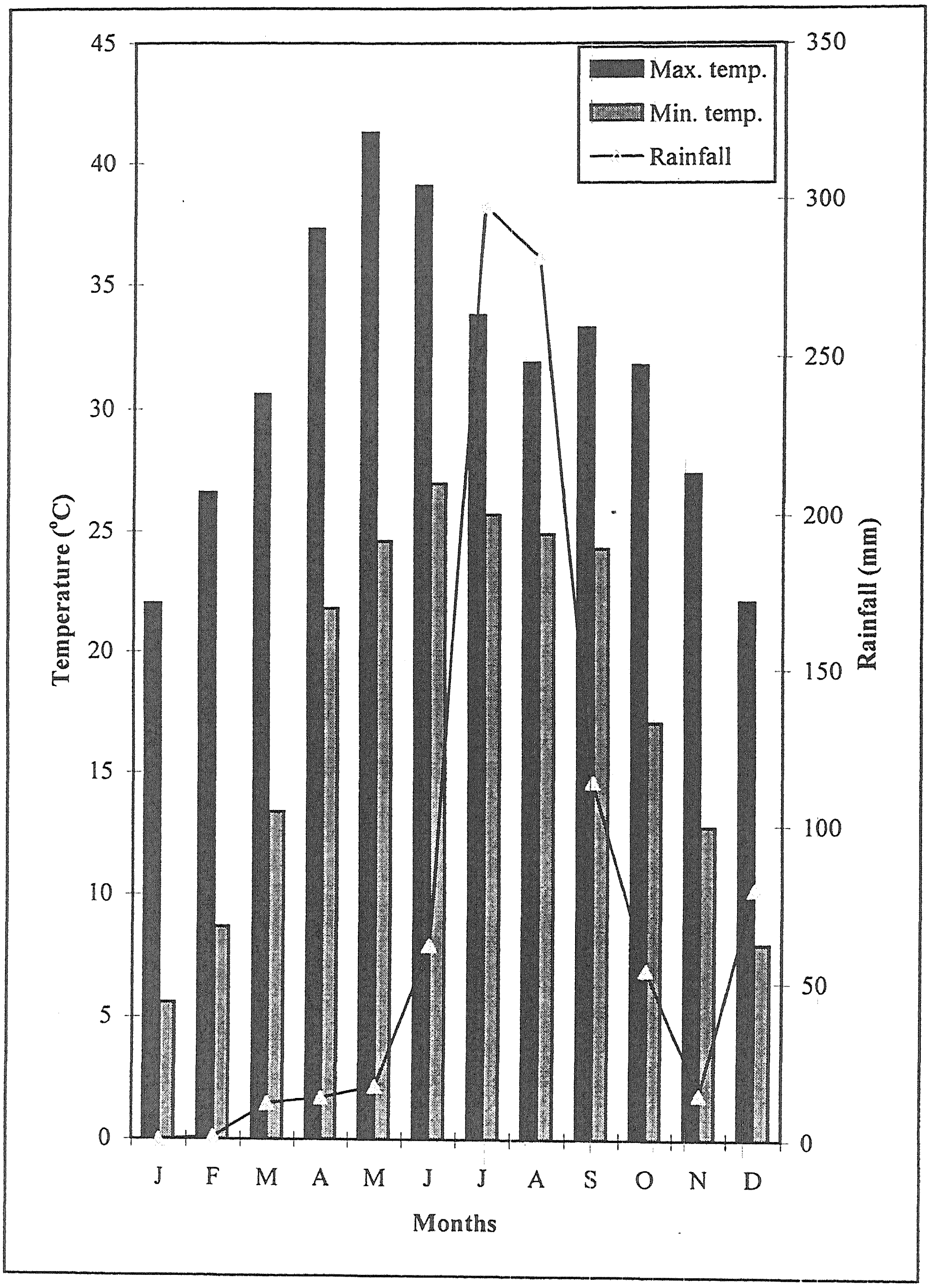


Fig. 2
Variation in mean monthly temperature and rainfall at the study site (1997-1998).

lowest relative humidity (55/26) followed by June (64/37). The wind velocity was maximum during June (7.6 km/hr) followed by May (6.8 km/hr) and July (5.5 km/hr). It was least during January (1.1 km/hr).

Brightness or sunshine was most during May (10.2 km/hr) followed by April (9.7 km/hr) and February (9.4 km/hr). Brightness was least during December (2.7 hr/day). Peak evaporation was recorded during May (11.5 mm/day) followed by June (10.5 mm/day). The rate of evaporation was higher than rainfall during months of January and February. This shows droughtness due to higher evaporation need compared to rainfall receipt during these months.

Soil

The soil of the area was mainly red gravelly (alfisols) with good porosity and drainage and in some places it had semi-rocky substratum. The range and value of soil physical and chemical characteristics of the study site are given in Table 2. It was almost neutral with about 26.7 per cent water holding capacity. The soil nutrient status was in low to medium range (organic carbon 0.34%, available nitrogen 0.006%, available phosphorus 2.1 ppm).

The Plant Components

Tree

Acacia tortilis (Forsk.) Hayne (Family: Leguminosae, Sub-family: Mimosoideae) is an exotic tree introduced from Israel to India. It is commonly known as *Israeli babool* (India), *Haaken-steekdoring* (South Africa), Umbrella thorn (Africa), *Sayal* or *Samor* (Egypt and Sudan) and *Seyal* (Arabian countries). The original home of this tree is Israel, Sudan, Ethiopia, Somalia, Kenya, Tanzania and Arabian countries.

This plant is widely distributed in Middle East, Sahel, Sudan, Eastern and Southern Africa. In India it was first introduced in Western Rajasthan in 1958, and is now being widely planted in arid/semi-arid zones of Gujarat, Haryana,

Table 2
Average soil physical and chemical characteristics at the study site.

Parameter	Range	Average
Texture		
Sand (%)	26.2 - 81.4	49.2
Silt (%)	21.4 - 37.5	27.0
Clay (%)	11.3 - 41.6	23.8
Bulk density (g/cc)	1.05 - 1.14	1.09
pH	6.90 - 7.20	7.05
Nutrients		
Organic matter (%)	0.8200 - 1.07	0.93
Organic carbon (%)	0.4700 - 0.63	0.52
Total nitrogen (%)	0.0880 - 0.123	0.10
Available nitrogen (%)	0.0370 - 0.043	0.039
Total phosphorus (%)	0.0030 - 0.007	0.003
Available phosphorus (%)	0.0003 - 0.0008	0.0006
Total potassium (%)	0.1800 - 0.47	0.30
Total calcium (%)	0.2300 - 0.62	0.42
Available calcium (%)	0.1650 - 0.221	0.20

Tamil Nadu, Andhra Pradesh and Uttar Pradesh (NAS 1980; Ram Prakash and Drake Hocking 1986).

Botany

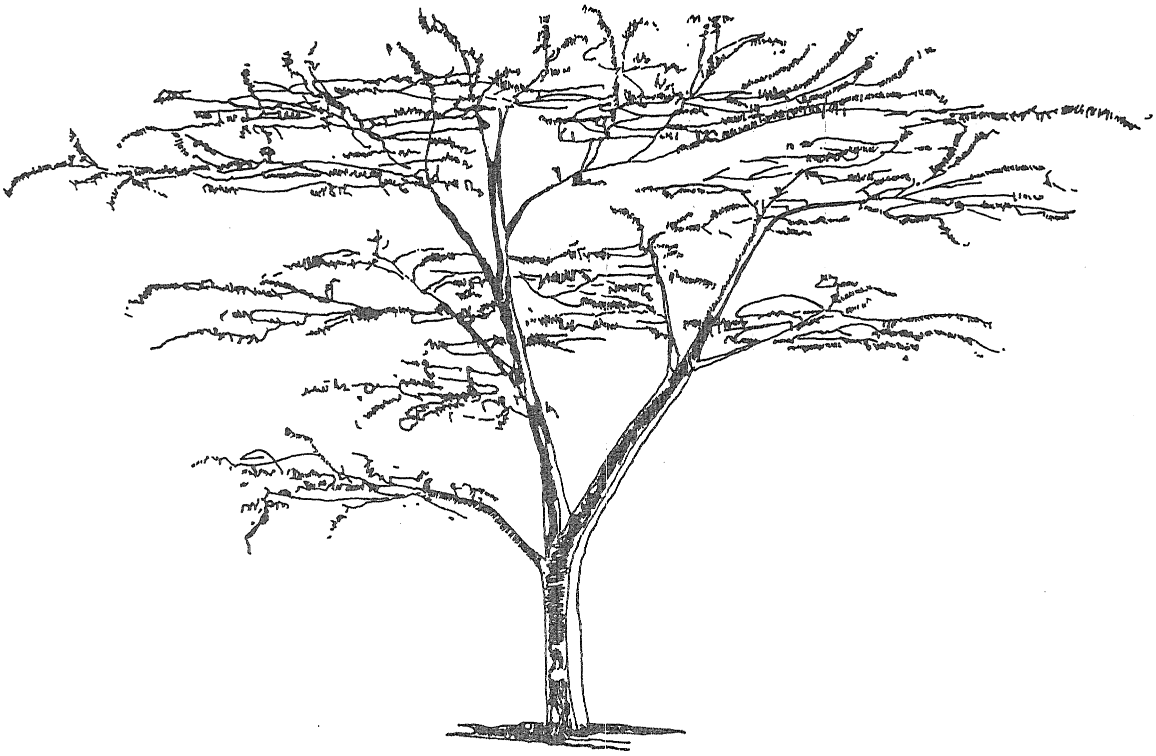
It is a medium sized tree, 4-15 m tall, sometimes with several trunks that spray upwards and out wards, fountain like, that support a flat-topped, evergreen umbrella of feathery foliage. Under extreme aridity it becomes a small shrub, often barely 1 m tall. The branchlets are reddish brown. The leaves are pinnately compound, 1.25-3.75 cm long, pinnae in three to ten pairs, with 7 to 15 pairs of small linear leaflets. The fragrant white or creamish flowers are born singly or in clusters in the month of October to November. Pods are contorted or spirally twisted like a coil spring, slightly constricted between the seeds, circular in cross section, 7.15 to 15 cm long, 0.6 to 0.8cm thick, ripening in November to February. It starts fruiting at the age of 6-8 years. Its thorns are a distinguishing feature. These are of two kinds - one being long, straight and white, and the other small, brownish and hooked (Fig. 3) (NAS, 1980; CSIR, 1985).

Environmental Requirements

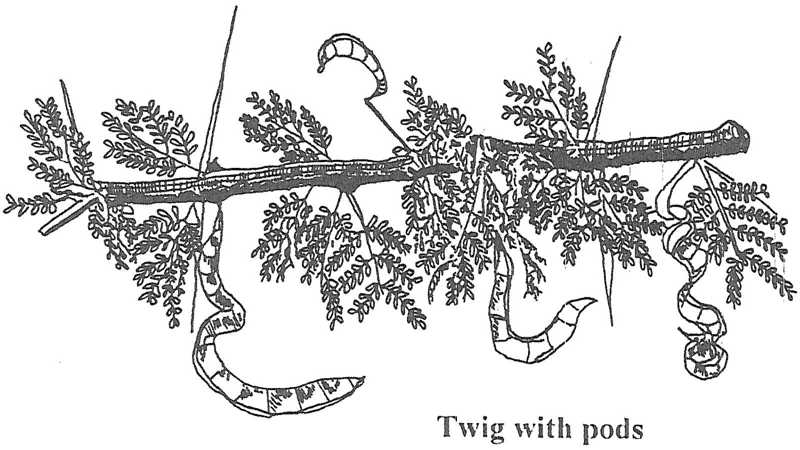
This species grow well in hot, arid climates where the temperature may range from 50 °C (maximum) to 0 °C (minimum). Plants less that 2 years old are easily damaged by frost and require protection. This species is best adapted to the lowlands. It thrives where rainfall is up to 1000 mm. The tree can also grow in alkaline soils (NAS, 1980; Chatterjee and Das, 1989).

Establishment

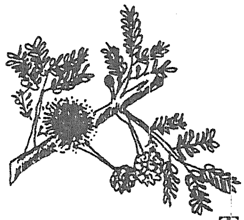
The freshly collected ripe seeds take much time to germinate, which is mainly due to thick seed coat. Scarified seeds give fast germination. Hot water treatment (80 – 90 °C) and concentrated sulphuric acid treatment (15-25 minutes) have been recommended for over 75 per cent germination. (Roy and Pathak,



Tree



Twig with pods



Twig with flower and bud

5 cm

Fig. 3
Acacia tortilis (Forsk.) Hayne

1990). The early seedling growth requires carefully mixed soil and nutrients in container which may be earthen, metallic or polythene bags; two seeds are usually sown in each container or bag and surplus germination pricked-out to empty ones. Sowing is generally done in July-August and seedlings are ready for planting out when they are 0.5 to 1.0m height in about 10 months (Ram Prakash and Hocking, 1986).

Economic Uses

Wood

The dense, red heartwood of this species has high calorific value (4400 kcal/kg) and makes superior firewood and charcoal used in different parts of the world. The wood is moderately heavy (700 kg/m^3) and is used for fence posts, agricultural implements and small articles (NAS, 1980). The bark is a rich source of tannin (CSIR, 1985)

Fodder

Pods are produced prolifically. They fall to the ground and are devoured by wild herbivores and goats, sheep and other domestic livestock. They provide sustenance for wildlife in arid regions, having about 19 per cent crude protein. The foliage is also palatable. It is a major dry season fodder for sheep and goats in the whole Sahara-Sahelian belt in the Sudan. The thorny branches are used to pen cattle, goats and sheep (NAS, 1980; Ram Prakash and Hocking, 1986).

Medicinal values

The stem bark of *Acacia tortilis* which is used against asthma in Somalia has been found to contain two new pharmacologically active compounds *viz.*, Quracol A and Quracol B. Both compounds inhibited electrically induced contraction of isolated guinea-pig ileum (Hagos *et al.*, 1987).

Other uses

It is an excellent species for sand dune stabilization, for shelterbelt and for strip planting along railway lines, canals and roads in sandy arid areas and for ravine and soil conservation bund plantings in rocky, shallow red soil areas (Kaul, 1980; Dagar *et al.*, 1994). Thorny branches are used as fencing material. Tender immature seeds are used as vegetable (Singh, 1994).

Principal enemies

Beraladae similis (Lepidoptera) larvae completely defoliate young plant of *Acacia tortilis* during August-October and October-March in sub-tropical region of India. The bagworm (*Cryptothelia crameri*) is a polyphagous pest all over India. Bruchids are the most serious pest of seed. Seed production is severely affected if bruchids are not checked in time. The pest can be controlled by the spray of 0.25 per cent Sevin 50WP or Folithion 50 EC (Pandey and Shivanker, 1994). Powder post beetles (*Sinoxylon anale* and *S. crassum*) attack *Acacia tortilis* timber within few weeks of its felling and convert it into dust thus rendering it useless as firewood. A wood boring insect *Xylodectus ornatus* attack *Acacia tortilis* and damage this tree (Patel and Dodia, 1999). Prophylactic treatment of 1.5% Lindane/Endosulfan protect the timber from borer attack for nearly a year (Singh and Bhandari, 1987).

Agroforestry applications

At wide spacing and with its thin canopy, *Acacia tortilis* offers good potential for taking a under crop of a short duration fodder or pulse during brief rainy season, or even a dryland cereal crop where soil conditions permit. Its tap rooting habit and nitrogen fixing character suggest that it could be suitable for under crops. Canopy management by lopping can enhance performance of under crops (Ram Prakash and Hocking, 1986)

Sand dune stabilization

Pasture Grasses

***Cenchrus ciliaris* Linn.**

This genus belongs to the tribe paniceae in which the two flowered spikelets fall when ripe leaving no glumes. The spikelets are solitary and pedicels are never swollen (Skerman and Riveros, 1992). It is commonly known as buffel grass or *anjan* grass and is very palatable when young and remains fairly palatable at maturity. It makes reasonable quality hay when cut in early flowering stage. It s persistence, deep rooting habit, resistance to drought and trampling are the other main attributes (Skerman and Riveros, 1992).

***Chrysopogon fulvus* (Spreng) Chiv.**

It has densely tufted culms bearing long linear acuminate leaves. The species presents some difficulty for taxonomist owing to its variability not only in vegetative parts but also in the size of spikelets and anthers (Bor, 1960). It is commonly known as *dholu* grass. The grass is a valuable fodder and is cut just before flowering. It may also be used as a sand binder (CSIR, 1950).

***Dichanthium annulatum* (Forsk.) Stapf.**

It has slender erect culms, nodes usually bearded, two to four racemes, erect and rather close, pedunculate, first glume of the spikelet not in durate. Stalks of racemes hairy, pedicellate spikelet usually male or bisexual, sometimes neuter but with both glumes well developed and often with lemmas (Skerman and Riveros, 1992). It is quite a palatable grass and widely used as hay in India. It is widely adaptable, tolerant to alkaline soils and is effective in erosion control (Skerman and Riveros, 1992).

***Heteropogon contortus* (L.) Beauv. ex. Roem. and Schult.**

A caespitose perennial, the culms erect to 75 cm, branching above, leaf sheaths keeled, glabrous. Raceme solitary, 3.5-15 cm long with up to 10 pairs of

awnless spikelets at base and an equal number of pairs above. Fertile sessile spikelets having awns 5-10 cm long .The grass is palatable in early vegetation stage but unattractive as it matures. Besides fodder its main attributes are hardiness, perenniality, tolerance to fire and ability to grow on poor soils (Skerman and Riveros, 1992).

***Sehima nervosum* (Willd.) Stapf.**

In this species culms are densely tufted with leaf blades upto 30 cm. Racemes solitary, 7-12 cm long, sessile spikelets pale green, with long bristles from the upper glume, and an awn about 45 mm long from the lemma, pedicelled spikelets purplish (Skerman and Riveros, 1992). It is one of the most palatable grasses in India and disappears quickly under grazing. It is also one of the important grasses for hay making (Dabadghao and Shankarnarayan, 1973).

Methods

Soil Studies

The soil samples were taken from two different depths *viz.*, depth 1 (0-15 cm.) and depth 2 (15-40 cm). The samples were taken by post-hole auger. Before taking soil samples all plants were cleared on the land surface, except the roots and organic matter embedded in horizon A. The soil sample for analysis of texture and other physical parameters were taken in the beginning and at the end of the investigation.

The texture analysis was done by Bouyoucos Hydrometer method as prescribed by Piper (1966). Soil pH was determined by using digital glass electrode pH meter at 1:2.5 soil-water ratio. Electrical conductivity from supernatant of the soil solution was determined by using a conductivity bridge. Soil moisture was observed by drying a known weight in a hot air oven (105 °C) till constant weight. Bulk density of soil was also determined following method outlined by Piper (1966).

Organic carbon was estimated by Walkley and Black's rapid titration method (Jackson, 1973). Total nitrogen was determined by Kjeldahl method while total phosphorus, potassium and calcium were determined by wet digestion method described by Jackson (1973). Phosphorus was estimated through the vanadomolybdophosphoric yellow colour method and intensity of yellow colour was read on Spectronic-20 at 470 nm against a blank sample. Potassium dihydrogen phosphate (KH_2PO_4) was used to develop standard curve for further calculations. The quantitative estimations of potassium and calcium was carried out by using the diluted stock solution into flame photometer. The amount of potassium and calcium was calculated from the standard curve prepared from potassium chloride and calcium chloride respectively. Available nitrogen was determined following alkaline permagnate method described by Piper (1966). The available phosphorus was determined following Olsen *et al.* (1954). The intensity of blue colour was read at 660 nm on spectronic-20 against a blank. The amount of available phosphorus was calculated from the standard curve prepared with $KH_2 PO_4$. The available calcium was determined by ammonium acetate extract method described by Piper (1966).

Microclimate Studies

The microclimatic parameters *viz.*, photosynthetically active radiation (PAR), air temperature, soil temperature and relative humidity (RH) were measured at fortnightly intervals on clear sky days. The PAR was recorded by Radio Quantum Photometer (LI-185B, USA). Air and soil temperatures were recorded by infrared thermometer and RH was measured by using a dial type self-indicating hair hygrometer.

Plant Growth Studies

Tree Growth

Growth data were recorded at six monthly interval. Height was measured by a calibrated meter rod. Collar diameter (cd) was measured at the 5 cm of stem base and diameter at breast height (dbh) at 135 cm height above ground level with the help of a tree caliper. Canopy spread was measured by measuring tape. The mean annual increment (MAI) was also calculated (Mac Dicken *et al.*, 1991).

Pasture Growth

During September of each year ten quadrates (1 m^2) were taken randomly at each microsite. The constituent species (five perennial grasses, annual grasses, legumes and weeds) were listed and counted. In perennial grass, each tiller was considered as an individual plant. Observations were made on growth characteristics of perennial grasses at each microsites by measuring height, tussock diameter and counting number of tiller.

The height of plant was measured in centimeter from the ground level to top growing points. The length and breadth of the tussock was measured in centimeter and the average value was calculated to represent the diameter. The number of tiller per plant in grasses was counted just before each harvest.

Biomass Studies

Aboveground Biomass

Tree

Sample trees, representing different diameter classes across the study site, were felled during February/March in each year following methods prescribed by Newbould (1967). After felling, the main bole, leaves and branches were separated. The main bole was cut into 1 m long segments starting from the base. Fresh weight of bole, branches and leaves were recorded in the field. A 5 cm wide disc from each bole segment was taken and weighed separately. The discs were

dried in a hot air oven at 60 °C till constant weight. The oven dried samples were weighed for dry matter determination. Similarly, samples from branches and leaves (about 100g) were taken for determination of dry matter.

Pasture

The understorey aboveground biomass was recorded by harvesting the whole plot and then weighing the pasture (perennial and annual grass) and weed (including legume forbs) separately. Fresh weight of herbage composition was recorded in the field using spring balance. Samples (about 100g) were taken and dried in hot air oven at (60 °C) till constant weight. The oven dry samples were weighed for dry matter determination.

Belowground Biomass

Tree

The sample trees were excavated (up to 1.5 m) for belowground biomass studies. The total roots were taken out and washed with water, then exposed in sunlight for two hours to remove surface moisture. The tap root was cut into upper, middle and lower segment and their weight was recorded in field. Samples were taken from these segments in the form of disc for dry matter determination. The secondary and tertiary roots were also weighed. The samples were dried in a hot air oven (60 °C) till constant weight. The oven dry samples were weighed for dry matter determination.

Pasture

The below ground biomass of pasture was recorded by excavating monoliths (30 cm^3). The roots were washed with water then exposed in sunlight (2 hrs) for removing surface moisture. The grass roots and distributed tree roots were separated. The samples (about 100 g) were dried in a hot air oven (60 °C) till

constant weight. The oven dry samples were weighed for dry matter determination.

Litter Production Studies

Litter production was estimated by collecting litter samples at fortnightly interval from a litter trap of painted steel wire net of 1 m^2 collecting area and 1.5 mm mesh size. The litter traps were placed tree's continuous canopy and were raised 6 inches above the ground level on wooden frames to permit drainage of water without any litter loss and to avoid the action of soil fauna and the effect of soil splash. Sides of wire net were surrounded with wooden frame of 15 cm height. The collected litter was weighed, air dried and stored in paper bags. At monthly interval, the litter was separated into leaf, branch and miscellaneous (pod, buds, flowers etc.) which were weighed separately. The litter of each category was oven dried (60 °C) till constant for dry matter determination (Mc Shane *et al.*, 1983).

Plant Nutrient Studies

Oven dried and powdered plant and litter samples were taken for nutrient (N, P, K, Ca) analysis. Nitrogen content was estimated by following Kjeldahl method prescribed by Piper (1966). For estimation of phosphorus, potassium and calcium, 1 gram of plant litter material was digested in 70 per cent perchloric acid on a hot plate till solution turned colourless. The contents were cooled and then volume was made up to 100 ml in a volumetric flask as stock solution. Phosphorus was estimated by the method prescribed by Jackson (1973) and the intensity of yellow colour was read on Spectronic-20 at 470 nm against a blank. Potassium dihydrogen phosphate (KH_2PO_4) was used to develop standard curve for further calculations. The quantitative estimations of potassium and calcium was carried out by using the diluted stock solution into flame photometer. The

amount of potassium and calcium was calculated from the standard curve prepared from potassium chloride and calcium chloride, respectively.

Nutrient accumulation (kg/ha) in different plant parts and recyclable nutrients through litter were calculated by multiplying dry matter with average nutrient concentration.

Litter Decomposition

The studies on mass loss pattern of leaf litter of *Acacia tortilis* was conducted in laboratory and field conditions. The samples were air dried and weighed into 10 g working samples. These were then spread in 9x15 cm nylon net bags. In laboratory, the litter bags were surface buried in trays filled up with the soil from the respective field sites. These trays were then kept in a B.O.D. incubator (27 ± °C) under controlled RH conditions for 180 days. The trays were periodically watered to avoid complete dry condition. The bags were carefully recovered after every 30 days up to 180 days. In field, the litter bags were buried in the respective microsites during January/February 1997 at 1-2 cm depth. The bags were carefully recovered after every 3 months.

After recovering the bags, the remaining litter was air dried and weighed after removing the adhered soil particles etc. The nutrient analysis was done as per the standard procedure mentioned earlier. The nutrient release was calculated based on the per cent of nutrient in the initial litter content (Gupta and Singh, 1977).

CHAPTER 4

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

PART I

MICROCLIMATE

Climate is defined as the mean or average condition of the atmosphere, that is, the mean or average weather (Rosenberg, 1986). However, more inclusively, it is not only the mean weather but also a typical variability and the range of extreme exhibited by the state of the atmosphere in a particular area over a specific period of time. Climatic description, therefore, need to be framed over specific timed periods (anywhere from hours to centuries) for specific location (Griffiths, 1985). The applicability of different agroforestry/silvopastoral systems at any location depends on the atmospheric processes at these levels, from a macro scale monsoons to micro scale shading of adjacent crops/pasture (Miller, 1993).

The chief environmental factors of aerial environment of plants include solar radiation (light), temperature (air and soil), humidity and soil moisture. These are being discussed for the four microsites selected for this study.

Solar Radiation (Light)

One of the major controls of microclimate in agroforestry/silvopastoral systems is solar radiation. It is also the one that is subject to considerable control by men (Reifsynder, 1989). Photosynthetically active radiation (PAR) is defined as that part of electromagnetic spectrum with wavelength between 400 to 700 nm. It is that part of sun's energy that is trapped by green plant and upon which all life ultimately depends.

It is, therefore, extremely useful to know how the canopy of woody and non-woody components in silvopastures intercept this radiation. By knowing how much is intercepted one can calculate the photosynthetic efficiency of this system

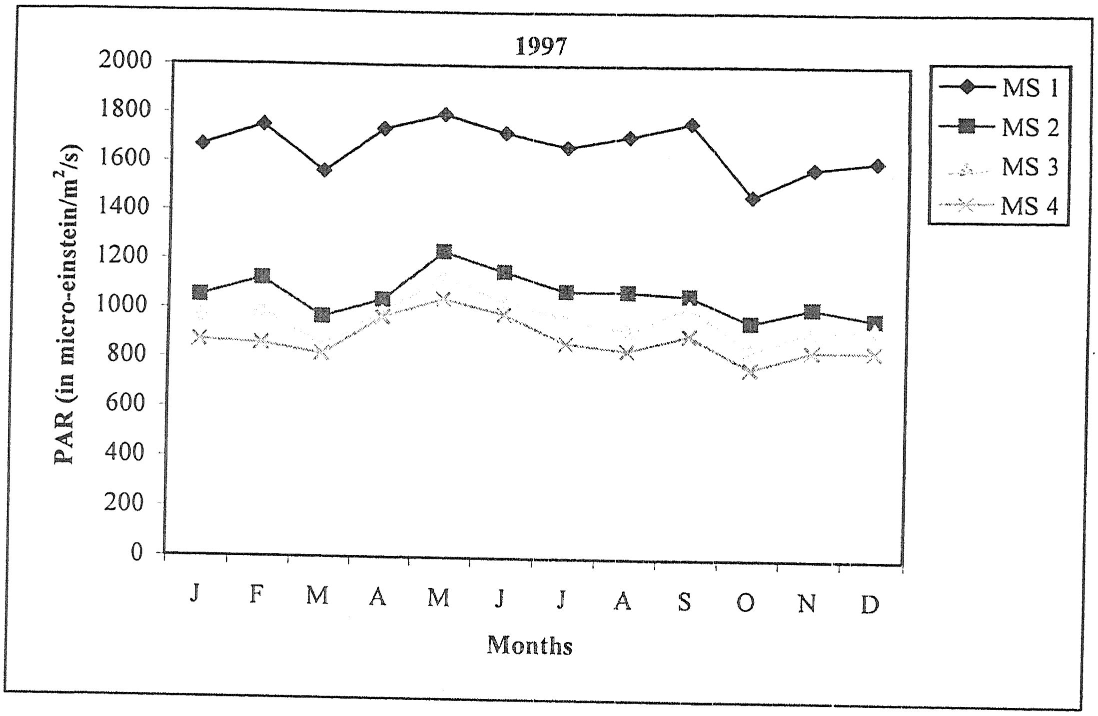
and match this against alternative canopy structures or theoretical models (Jackson, 1989).

The pattern of PAR availability to the pasture in different microsites during 1997 and 1998 is shown in Fig. 4. In open situation, peak values were recorded in May in both the years. Higher radiation was recorded in 1998 (1987 micro-einstein/m^2/s) when compare to 1997 (1800 micro-einstein/m^2/s). Highest mean annual PAR availability was recorded in open situation followed by light, medium and dense canopies of *Acacia tortilis* in both the years. In both the years the critical difference in PAR availability between open and under trees. However, difference under trees, significant difference was found only between light and dense canopies. The average reduction in PAR availability was found to be 31.1 per cent, 40.3 per cent and 43.6 per cent, respectively under light, medium and dense canopies of *Acacia tortilis* (Table 3).

Table 3
PAR availability under open and different canopy situations of *Acacia tortilis* (annual average) (in micro-einstein/m^2/s).

Canopy	1997	1998
Open	1671±98	1565±285
Light	1060±83	1078±212
Medium	963±80	977±186
Dense	883±79	868±163
	173	152

In agri-silvicultural study at IGFRI Jhansi, Hazra (1985) reported that moderate sized and spaced trees of *Albizia lebbek* allowed 80 per cent of PAR to underneath crops followed by *Acacia nilotica* (66 %) and *Leucaena leucocephala* (58 %). In another such study at IGFRI Jhansi, Hazra and Tripathi (1986) reported



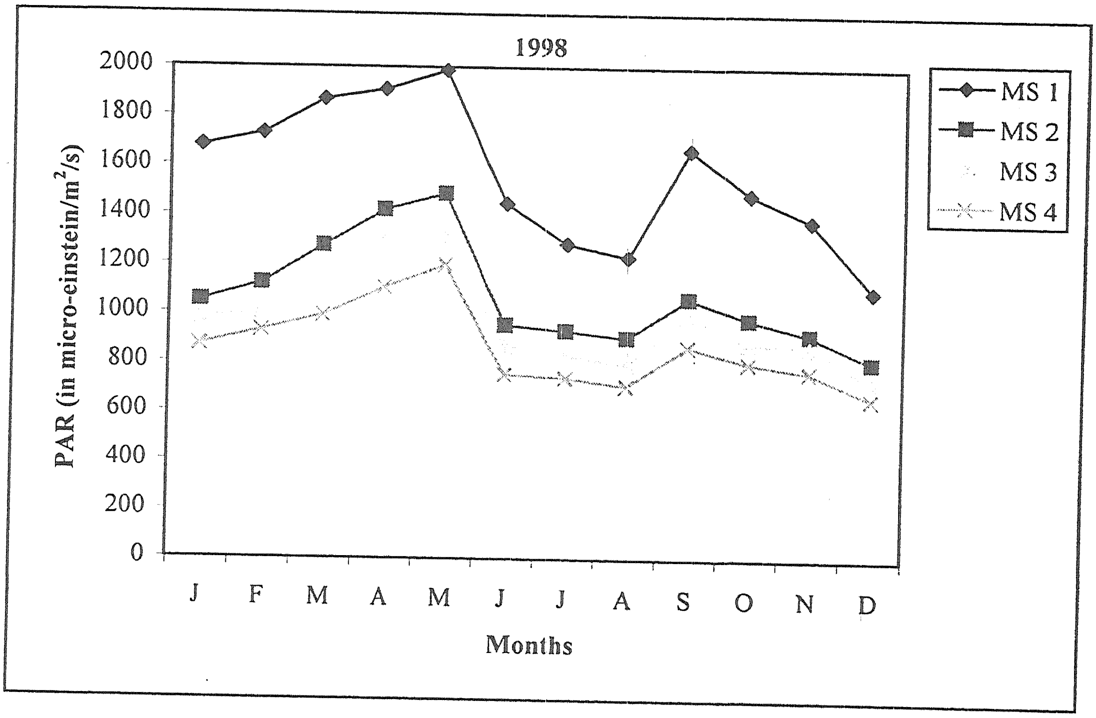


Fig. 4
Pattern of PAR availability to the ground vegetation at the four microsites of study (January-December).

that moderate sized and spaced tree of *Hardwickia binata* allowed 80 per cent PAR as compared to open situation. This was followed by *Acacia tortilis* (65 %) and *L. leucocephala* (48 %). In a silvopastoral study at IGFRI Jhansi, Mishra and Bhatt (1992) reported least PAR infiltration from well established and closely spaced trees of *Leucaena Leucocephala* (30 %) The other species *viz.*, *Albizia amara*, *Albizia lebbek*, *Hardwickia binata* and *Acacia tortilis* infiltered 35 per cent, 37 per cent 55 per cent and 60 per cent PAR, respectively.

Transmission of solar radiation through tree canopy depends on stand density but this relationship is not exactly linear in temperate species. A stand with 50 per cent of crown volume transmits less than 20 per cent incident solar radiation. With only 10 per cent of crown closure, certainly a rather open stand, radiation is reduced by 25 per cent. Thus it might be expected that even sparse stands would offer considerable protection from excessive radiation loads. On the other hand, crown closure of only one third could reduce solar radiation beneath by two third which may results into little radiation for same crops (Miller, 1959). It is, however, expected that in tropics where sun is close to zenith at noon, the relationship between transmitted light and crown closure would be close to linear (Reifsynder, 1989). Similar type of relationship has been observed in this study.

However, this situation is for direct and diffused solar radiation from a clear sky. On cloudy days when only diffused radiation is present at the top of the canopy, transmission is expected to be greater than that of clear days. It is because that diffuse light of sky can't find many more holes to come through than can direct beam of sunlight (Trapp, 1938).

The availability of solar radiation (especially the PAR) has important implications for productivity of understorey grasses and other vegetation in a silvopastoral system. By using this knowledge, potential of growing understorey pasture species in between the interspace of trees can be determined. The knowledge on special and temporal variation in PAR availability can be

effectively used in designing and optimization of both understorey and overall yields (Anderson, 1964).

Temperature

Temperature is like water in its action upon plant in that it has more or less to do with nearly every function, but as a working condition and not as a material. All the chemical processes of metabolism and also many physical processes such as diffusion are dependent upon temperature and get accelerated by its increased up to and optimum (Weaver and Clements, 1986). As a light, there is a daily and annual fluctuation in temperature. The amount of heat received depends upon the angle of sun's rays and their consequent absorption. The actual temperatures at the surface of the earth are greatly modify by radiation, conduction and convection (Pearson, 1930).

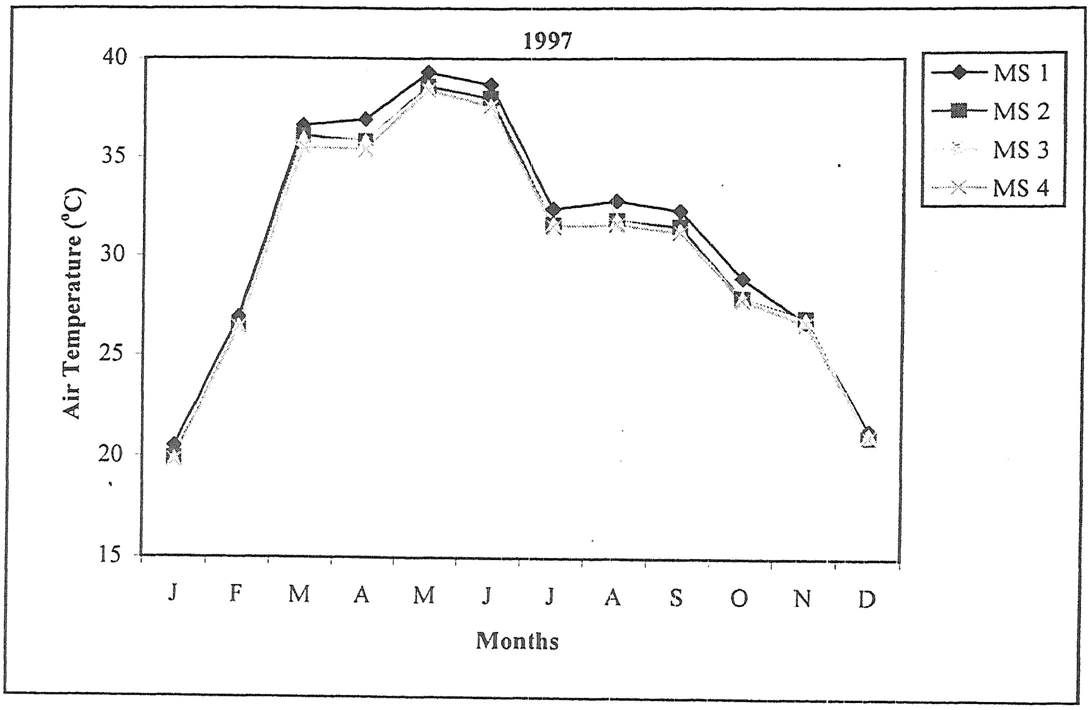
At micro scale, temperature (air and soil) are affected by tree canopies (Corlett and Ong, 1989). The temperature of the plants tends to follow closely that of environment.

Air Temperature

The air temperature was found to be highest in open situation in both the years (Fig. 5). This could be primarily because of full radiation, which maintained air temperature at a higher level. In silvopastoral systems, a decreasing level of air temperature was observed with the increase in tree density. In both the years, the critical difference in air temperature (annual average) between open and canopy situations was significant. However, the critical difference in different canopy situation was not significant in both the years (Table 4).

Soil Temperature

Soil temperature was found to be highest in open situation in both the years (Fig. 6). As in air temperature, this could be primarily because of full



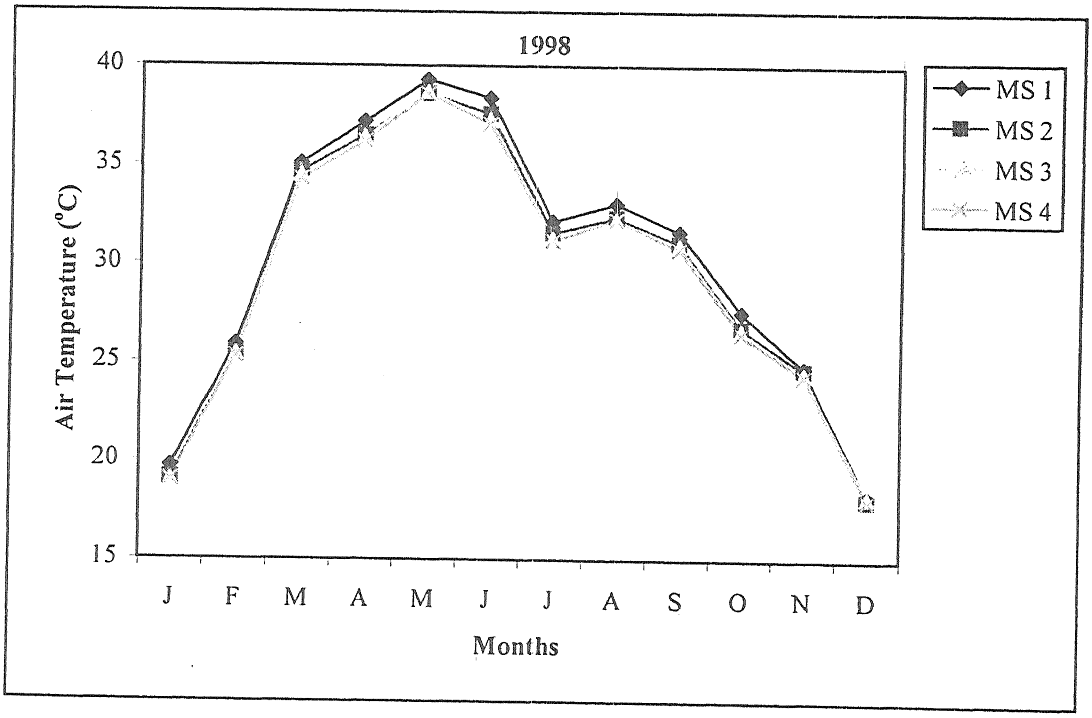
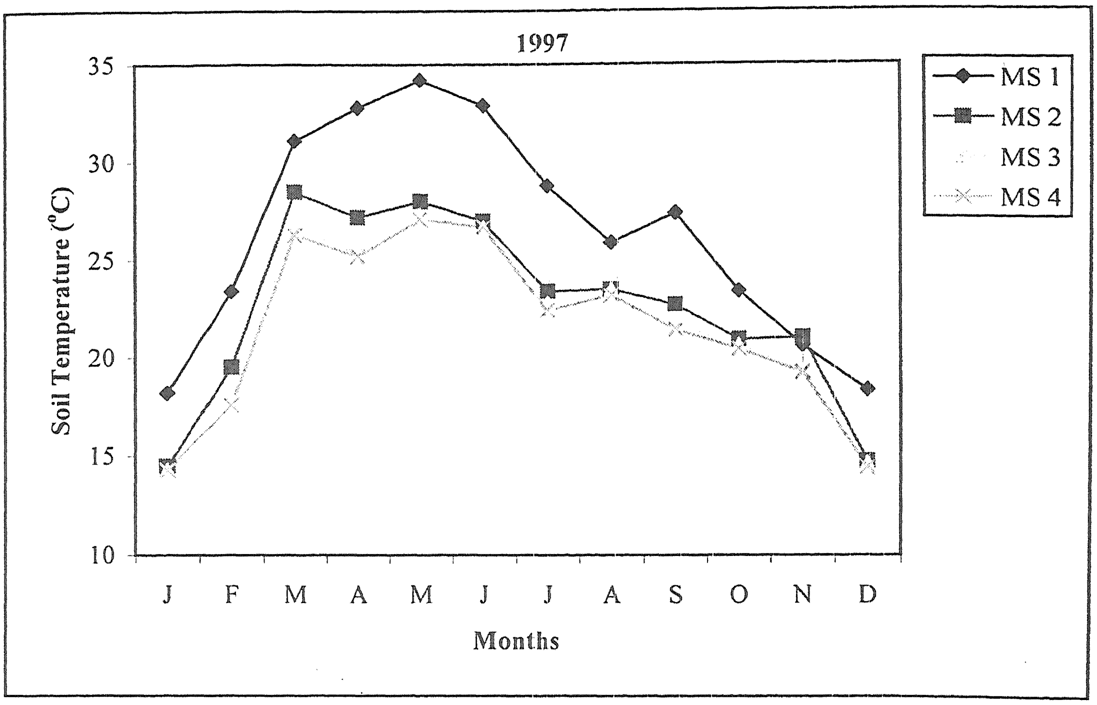


Fig. 5
Pattern of air temperature at the four microsites of the study (January-December).



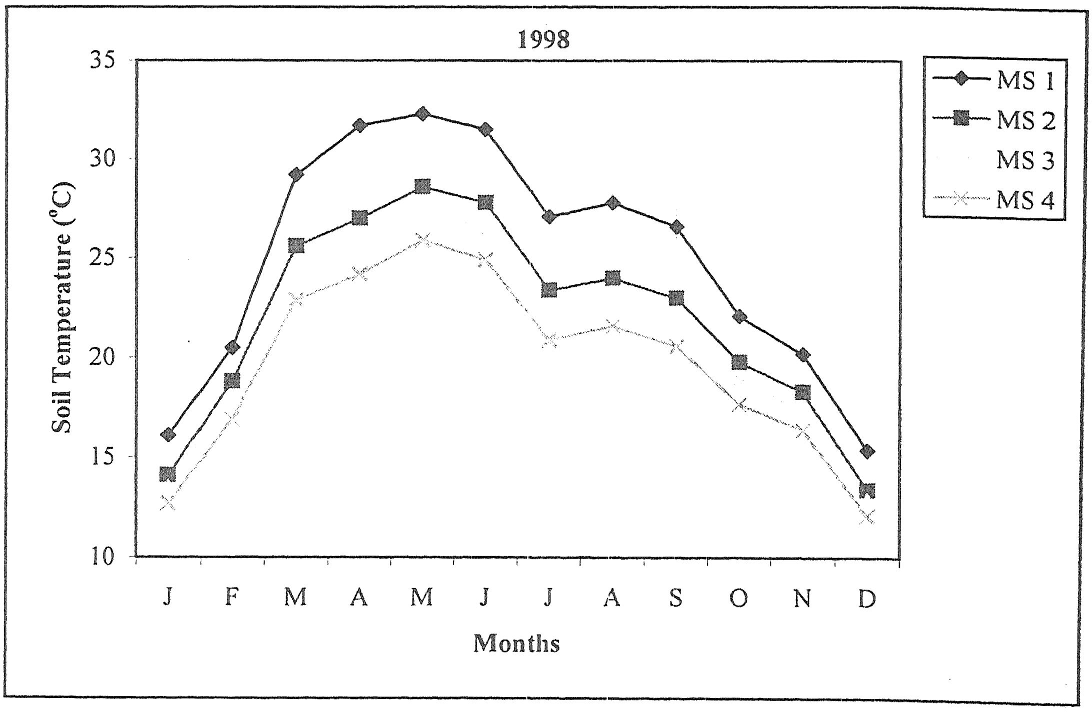


Fig. 6
Pattern of soil temperature at the four microsites of the study (January-December).

radiation which maintained soil temperature at a higher level. Similarly, in silvopastoral systems, a decreasing level of soil temperature was observed with the increase in tree density. In both the years, the critical difference in soil temperature (annual average) between open and canopy situations was significant. However, unlike the air temperature, the critical difference in different canopy situation was significant during 1998. In 1997 the difference were significant only between light and medium canopy (Table 5).

Table 4
Air temperature under open and different canopy situations of *Acacia tortilis* (annual average) (in °C).

Canopy	1997	1998
Open	31.1±6.4	30.3±7.0
Light	30.4±6.2	30.0±7.0
Medium	30.4±6.1	29.6±6.8
Dense	30.2±6.0	29.5±6.8
	0.3	0.4

Table 5
Soil temperature under open and different canopy situations of *Acacia tortilis* (annual average) (in °C).

Canopy	1997	1998
Open	26.4±5.7	25.0±6.0
Light	22.6±4.7	22.0±5.1
Medium	21.7±4.5	21.0±4.9
Dense	21.5±4.5	19.7±4.6
	0.5	0.6

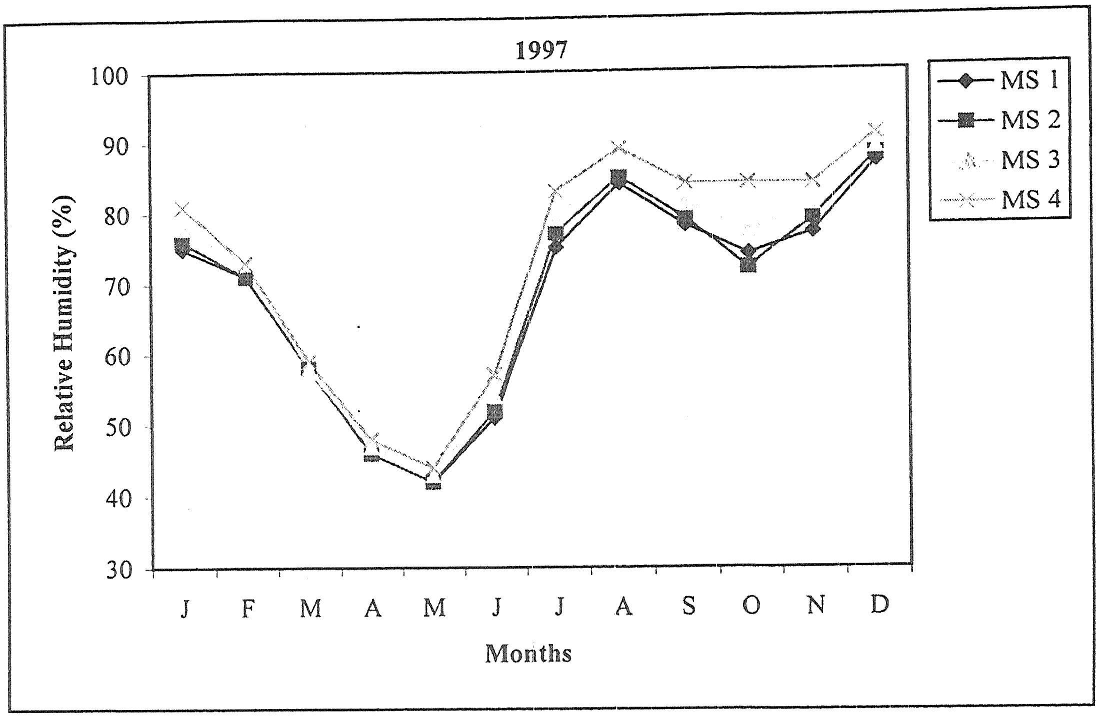
Similar trends in air/soil temperature under tree canopies have been reported by various workers. For instance, Hazra and Tripathi (1986) observed lower temperature regime under grown up canopies of *Albizia lebbek*, *Acacia nilotica* and *Leucaena leucocephala*. Mishra and Bhatt (1992) have also reported similar trends under the growing tree canopies of *Acacia tortilis*, *Hardwickia binata*, *Leucaena leucocephala*, *Albizia lebbek* and *Albizia amara*. Thus it would be seen that air/soil temperature is closely linked with the radiation availability in different microsites.

Relative Humidity (RH)

Humidity is one of the most important factor since it directly affect the rate of transpiration. The relative humidity (RH) is the ratio, expressed at percentage, of the water vapour actually present in the air (unit of space) at a certain temperature to the amount necessary to saturate the same unit of space under similar condition. Humidity is affected by a number of factors *viz*., wind, altitude, exposure, vegetation cover and soil moisture (Mitchell, 1936).

The RH was found to be highest in the dense canopy situation in both the years (Fig. 7). Lowest range of RH was observed in open situation. This could be primarily because of lower radiation levels received under the tree canopies. In silvopastoral systems, an increasing level of RH was observed with the increase in tree density. The critical difference in RH (annual average) between open and dense canopy situation was significant in 1998 only (Table 6).

Higher RH under tree canopy was reported by several workers. Ramakrishna and Sastri (1977) reported higher RH under mature *Acacia tortilis* trees in Rajasthan. Hazra and Tripathi (1986) reported higher RH under tree canopies *viz*., *Leucaena leucocephala* (80 %), *Acacia tortilis* (75 %) and *Hardwickia binata* (55 %) as compared to open situation (50 %). Similarly, Hazra and Patil (1986) observed more RH (62-70 %) under medium sized trees of *Albizia lebbek*, *Albizia procera*, *Leucaena leucocephala* and *Acacia tortilis* as



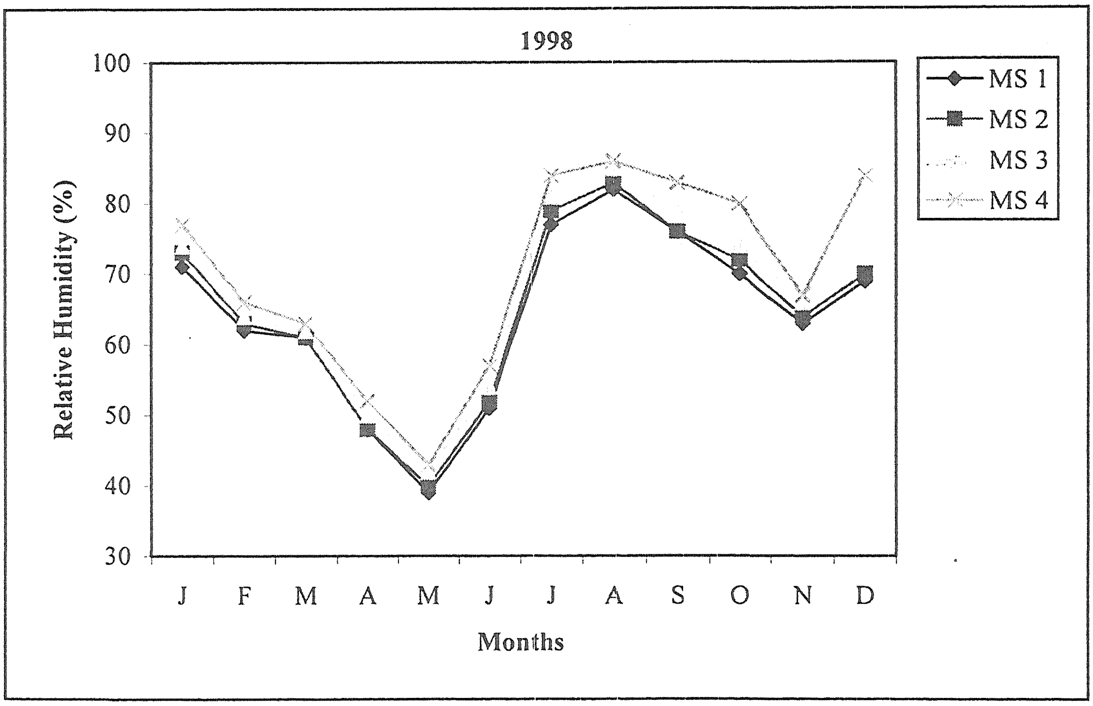


Fig. 7
Pattern of relative humidity at the four microsites of the study (January-December).

compared to open situation. Gill and Abrol (1987) reported higher RH below trees of *Prosopis juliflora* on salt affected soils in Haryana. The higher RH under tree cover was linked to lower radiation availability and more favourable soil moisture regime. In the present study the pattern of RH under different canopy density is correlated with radiation/soil moisture.

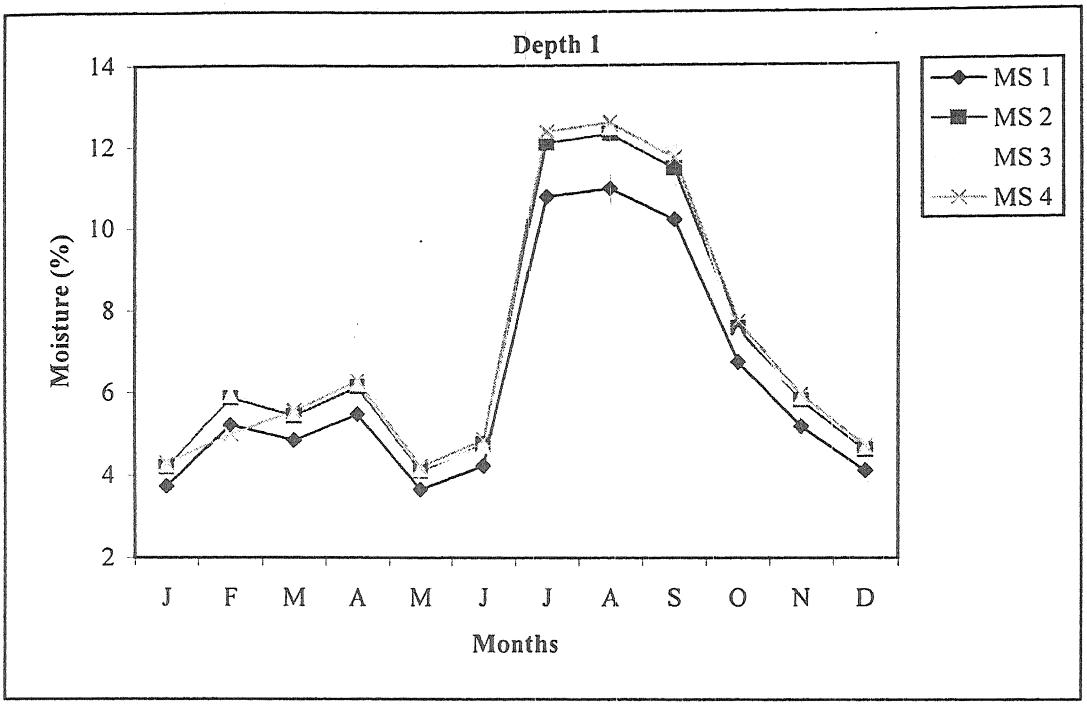
Table 6
Relative humidity under open and different canopy situations of *Acacia tortilis* (annual average) (%).

Canopy	1997	1998
Open	68±15	64±13
Light	68±15	65±13
Medium	70±15	68±14
Dense	73±16	70±14
	NS	5

Soil Moisture

The soil moisture is vital to plant growth not only because plants need water for their physiological processes but also because the water contains nutrients in solution. The pattern of soil moisture availability in different months at two depth (0-15 cm, 15-40 cm) during 1997 and 1998 are presented in Figs 8-9.

It is evident from the figures that soil moisture varied in different months at all the four microsites. During June to November the moisture availability was quit high as compared to the period during December to May. This may be attributed to the rainfall and evaporation pattern during the study period. The period June to November received over 87 per cent of total rainfall received. In a particular month, generally, more soil moisture was recorded under trees when



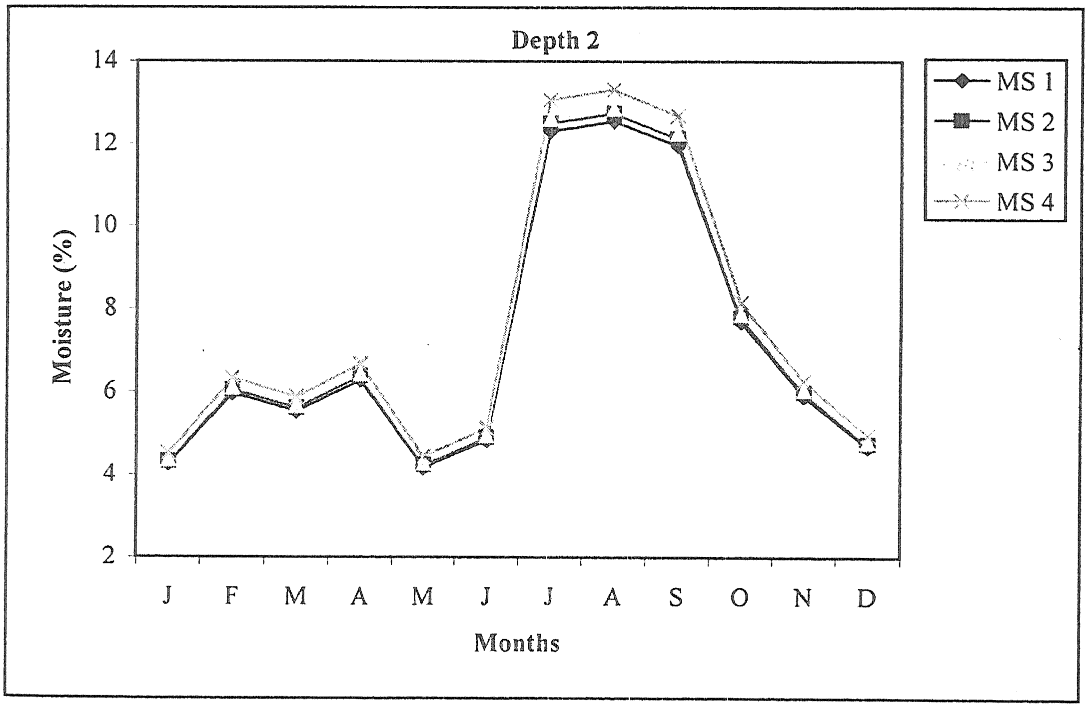
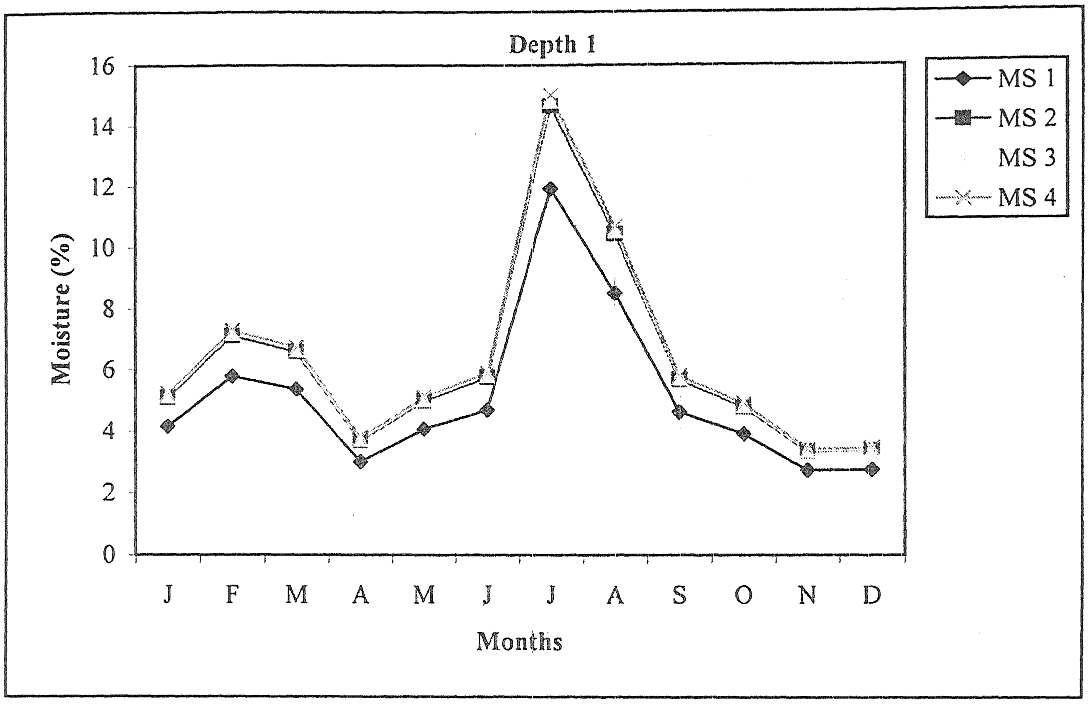


Fig. 8
Pattern of soil moisture availability at the four microsites of the study during 1997 (January-December).



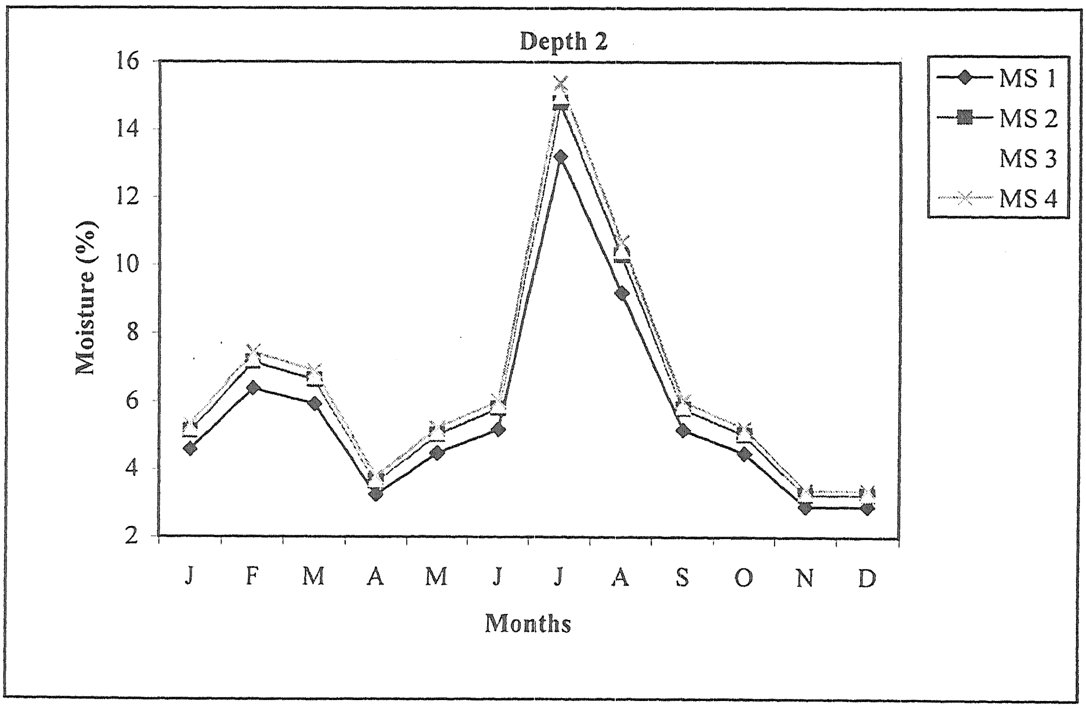


Fig. 9
Pattern of soil moisture availability at the four microsites of the study during 1998 (January-December).

compared to only pasture situation. Similarly, in silvopastures, a general increasing trend in soil moisture was found with increase in tree density.

Pattern of mean annual soil moisture in different depth at the four microsites is presented in Table 7.

In both the years, the critical difference in mean soil moisture (annual average) between open and canopy situations was significant at both the depths. In silvopastoral systems, the differences were not significant at depth 1 (0-15 cm). However, significant difference was observed in between light and dense canopy situation at depth 2 (15-40 cm) (Table 7).

Table 7
Mean annual soil moisture (%) under tree canopies of *Acacia tortilis* (1997-1998).

Microsite	Depth		
	D1	D2	Mean
MS 1	5.69	6.41	6.05
MS 2	6.66	6.80	6.73
MS 3	6.74	6.88	6.81
MS 4	6.81	7.09	6.95
CD ($P < 0.05$)	0.39	0.26	NS

Soil moisture content has been linked to density of natural vegetation cover (Cunnigham, 1963) and type of clay/organic matter present in the soil (Thompson and Troch, 1985). Higher soil moisture regime under trees and its increase with the depth may be attributed to this reason.

PART-II

PLANT GROWTH

Pasture Growth

Botanical Composition of Herbage

In terrestrial ecosystems (like silvopastures) vegetation constitute the second major component after land, people and cattle. In such ecosystems the herbaceous layer and non-leguminous part of woody shrubs and trees contribute towards fodder. The young and green succulent shoots of grasses and forbs of leguminosae provide the best choice for grazing material (Pandeya, 1988). The ground flora exhibit population fluxes due to succession. The botanical composition also keeps on changing because of external forces of harvesting, grazing, trampling, burning, lopping, browsing, shifting cultivation and timber removal (Singh and Misra, 1969). Thus studies on botanical composition of ground flora in silvopastures are of great significance for proper management and utilization of pasture component.

The botanical composition of ground vegetation at different microsites has shown that it could be grouped into grasses (both perennial and annual), legumes and weeds (Table 8). The number of perennial grasses was same in all the microsites. These were *Chrysopogon fulvus*, *Cenchrus ciliaris*, *Heteropogon contortus*, *Sehima nervosum and Dicanthium annulatum*. Also there was no appreciable difference in number of annual grasses, legumes and weeds in different microsites.

Immediately after the first monsoon showers, the seedling of annual and perennial grasses started sprouting and were followed by vigorous vegetation growth. Flowering started in the beginning of August/September, which continued into October. Fruiting was followed immediately after flowering. The rainy season annuals and shoots of many perennial species dried up in late October/early November and many remained as dead biomass until battered down as litter by wind. Decomposition of litter was hastened by winter showers. The

Table 8
List of species observed at the study site (1997-1998).

Plant Species	Microsites			
	MS 1	MS 2	MS 3	MS 4
Perennial Grasses				
Cenchrus ciliaris Linn.	+	+	+	+
Chrysopogon fulvus (Spreng) Chiv.	+	+	+	+
Dicanthium annulatum (Forsk.) Stapf.	+	+	+	+
Heteropogon contortus (L.) Beauv. ex. Roem. & Schult.	+	+	+	+
Sehima nervosum (Willd.) Stapf.	+	+	+	+
Annual Grasses				
Apluda mutica L.	+	+	+	+
Aristida adscensionis L.	-	+	-	+
Brachiaria mutica (Forsk.) Stapf.	+	+	+	+
Brachiaria ramosa (L.) Stapf.	+	-	+	+
Digitaria ciliaris (Retz.) Koel.	+	+	+	+
D. sanguinalis (L.) Scop.	+	+	-	-
Dactyloctenium aegyptium (L.) Willd.	+	+	+	+
Eragrostis pilosa (L.) P. Beauv.	+	+	+	+
Eragrostis tenella (L.) P. Beauv. ex. R.& S.	-	+	-	+
Echinochloa colona (L.) Link	-	+	+	-
E. crusgalli (L.) P. Beauv.	-	-	+	-
Eleusine indica (L.) Gaertn.	+	-	+	-
Polypogon monspeliensis (L.) Desf.	+	-	-	+
Setaria glauca P. Beauv.	+	+	+	+
Setaria intermedia R.& S.	+	+	-	+
Themeda quadrivalvis (L.) O. Ktze.	+	+	+	+
Legumes				
Alysicarpus monilifer (L.) DC.	+	+	+	+
Alysicarpus vaginalis (L.) DC.	-	+	-	+
Atylosia scarabaeoides (L.) Benth.	-	+	-	-
Goniogyna hirta (Willd.) Ali	+	-	+	+
Indigofera astragalina DC.	+	+	-	-
I. linifolia (L.f.) Retz.	-	-	+	-
I. linnaei Ali	+	-	+	+
Lathyrus apacha L.	+	+	+	+
Rhynchosia minima (L.) DC.	+	+	+	+
Senna tora (L.) Roxb.	+	+	+	+
Tephrosia purpurea (L.) Pers.	-	+	+	+
Tephrosia villosa (L.) Pers.	+	-	+	+
Vicia sativa L.	+	+	-	+
Vigna aconitifolia (Jacq.) Marechal	+	-	-	+

Contd. on next page

Weeds				
Achyranthes aspera L.	+	+	+	+
Ageratum conyzoides L.	+	+	+	+
Blainvillea acmella (L.) Philipson	-	-	+	-
Boerhavia diffusa L.	+	+	+	+
Borreria hispida (L.) F. N. Will.	-	+	-	+
Borreria pusilla (Wall.) DC.	-	+	+	-
Celosia argentea L.	+	+	-	+
Cleome viscosa L.	+	-	+	+
Cocculus hirsutus (L.) Diels.	+	+	+	+
Commelina benghalensis L.	+	-	+	+
Convolvulus microphyllus Sieb. ex. Spreng.	+	+	-	+
Corchorus aestuans L.	+	-	+	+
Cynoglossum denticulatum (L.) DC.	+	-	-	-
Cyperus rotundus L.	+	+	+	+
Cyperus triceps (Rotth.) Endl.	-	-	+	-
Eclipta prostrata (L.) L.	-	-	+	+
Enicostema axillare (Lamk.) Roynal	+	-	-	-
Euphorbia hirta L.	+	+	+	+
Evolvulus alsinoides (L.) L.	+	-	+	-
Gnaphalium purpureum L.	+	+	+	-
Justicia diffusa Willd.	+	+	+	+
Lantana camara L.	+	-	-	+
Launaea asplenifolia (Willd.) Hook. f.	+	+	+	-
Leucas aspera (Willd.) Spreng.	+	-	+	+
Oldenlandia corymbosa L.	+	+	-	-
Parthenium hysterophorous L.	+	+	+	+
Phyllanthus fraternus Webster	+	+	+	+
Portulaca oleracea L.	+	+	+	-
Sida cordifolia L.	+	-	+	+
Sida acuta Burm. f.	-	-	-	+
Trichodesma indicum (L.) R. Br.	+	+	+	+
Tridax procumbens L.	+	+	+	+
Urena lobata L.	+	-	-	+
Vernonia cinerea (L.) Less.	+	+	-	-
Vicoa indica (L.) DC.	+	+	+	+

(+ = Present; - = Absent)

winter season annual germinated by this time and there was tillering of perennial grasses. The phenological pattern observed in this site coincides well with other monsoonic grassland/grazing land in India (Singh and Yadav, 1974).

Table 9 presents the data on mean herbage composition at different microsites. It is evident from the table that total density of ground vegetation was higher in open situation when compared to the canopy situation. The share of perennial and annual grasses decreased markedly under dense canopy situation. However, share of legumes and weeds increased in canopy situation.

Singh *et al.* (1985) had studied botanical composition of herbage under *Pinus roxburghii* plantation in Himachal Pradesh. They found higher density of herbage in open situation as compared to canopy situation. Similarly, floristic composition of herbaceous vegetation under *Quercus incana*, *Cedrus deodara* and *Pinus roxburghii* was studied by Singh and Verma (1986) in Himachal Pradesh. They also found similar results. The botanical composition of herbage under tree canopy of *Leucaena leucocephala* and *Acacia tortilis* has been studied at Jhansi (Singh *et al.*, 1990). A decrease in share of perennial grasses under trees was reported, higher decrease being noticed under *Leucaena leucocephala*. The total density was also reported to be higher under open situation.

Vigour of Perennial Grasses

Aboveground

After stand structure, plant vigour of prominent perennial grass species is an important attribute of grassland/silvopasture. It indicates the role of species in forage production and management. Several workers have studied effects of certain practices like grazing (Hazella, 1967), defoliation (Deb Roy *et al.*, 1975) and nutrient application (Shankarnarayan *et al.*, 1975, 1976) on grass vigour in some grasslands of India. Vigour attributes *viz.*, plant height, tussock diameter, number of tiller/tussock for all the five perennial grasses were studied at the four microsites. These are being discussed as under:

Table 9
Mean herbage composition of *Acacia tortilis* based silvopastoral system at the study site (1997-1998).

Attributes	Microsites of study			
	MS1	MS2	MS3	MS4
Number of plant (/m^2)				
(i) Perennial grasses	5	4	4	4
(ii) Annual grasses	3	4	4	4
(iii) Legume forbs	5	3	3	3
(iv) Weeds	6	9	9	11
Total density (no/m^2)	417	343	328	307
Density shared by (%)				
(i) Perennial grasses	80.8	71.6	66.3	62.8
(ii) Annual grasses	7.6	13.9	14.4	18.4
(iii) Legume forbs	4.1	5.6	4.8	5.6
(iv) Weeds	7.5	8.9	14.6	13.2

Plant Height

The average height, tussock diameter and number of tillers at different microsites are presented in Fig. 10 Average grass height varied from 53.2 to 62.4 cm. More height was recorded in open situation when compared to canopy situation. In silvopastures, a consistent trend of decrease in height was observed under silvopastures with increase in tree density.

Table 10 presents data on average growth characteristics of individual grasses in different microsite of study. At microsite 1, peak average height were exhibited by *Chrysopogon fulvus* (77.1 cm) followed by *Cenchrus ciliaris* (67.9 cm), *Heteropogon contortus* (60.5 cm), *Sehima nervosum* (55.2 cm) and *Dicanthium annulatum* (55.1 cm). At microsite 2, peak average height was exhibited by *Chrysopogon fulvus* (74.5 cm) followed by *Cenchrus ciliaris* (58.2 cm), *Heteropogon contortus* (57.6 cm), *Sehima nervosum* (53.2 cm) and *Dicanthium annulatum* (49.4 cm). At microsite 3, peak average height was exhibited by *Chrysopogon fulvus* (73.8 cm) followed by *Heteropogon contortus* (54.2 cm), *Sehima nervosum* (52.6 cm), *Cenchrus ciliaris* (50.4 cm) and *Dicanthium annulatum* (46.6 cm). At microsite 4, peak average height was exhibited by *Chrysopogon fulvus* (71.7 cm) followed by *Sehima nervosum* (51.7 cm), *Heteropogon contortus* (51.4 cm), *Cenchrus ciliaris* (47.4 cm) and *Dicanthium annulatum* (44.2 cm).

The height growth showed a decreasing trend with increase in canopy density. Such differences between the microsites could be because of the varying microclimatic conditions prevailing on these sites. Similar differences in grass vigour has been reported by several workers in arid and semiarid conditions (Gupta and Saxena, 1972; Kanodia, 1981; Trivedi and Gupta, 1994).

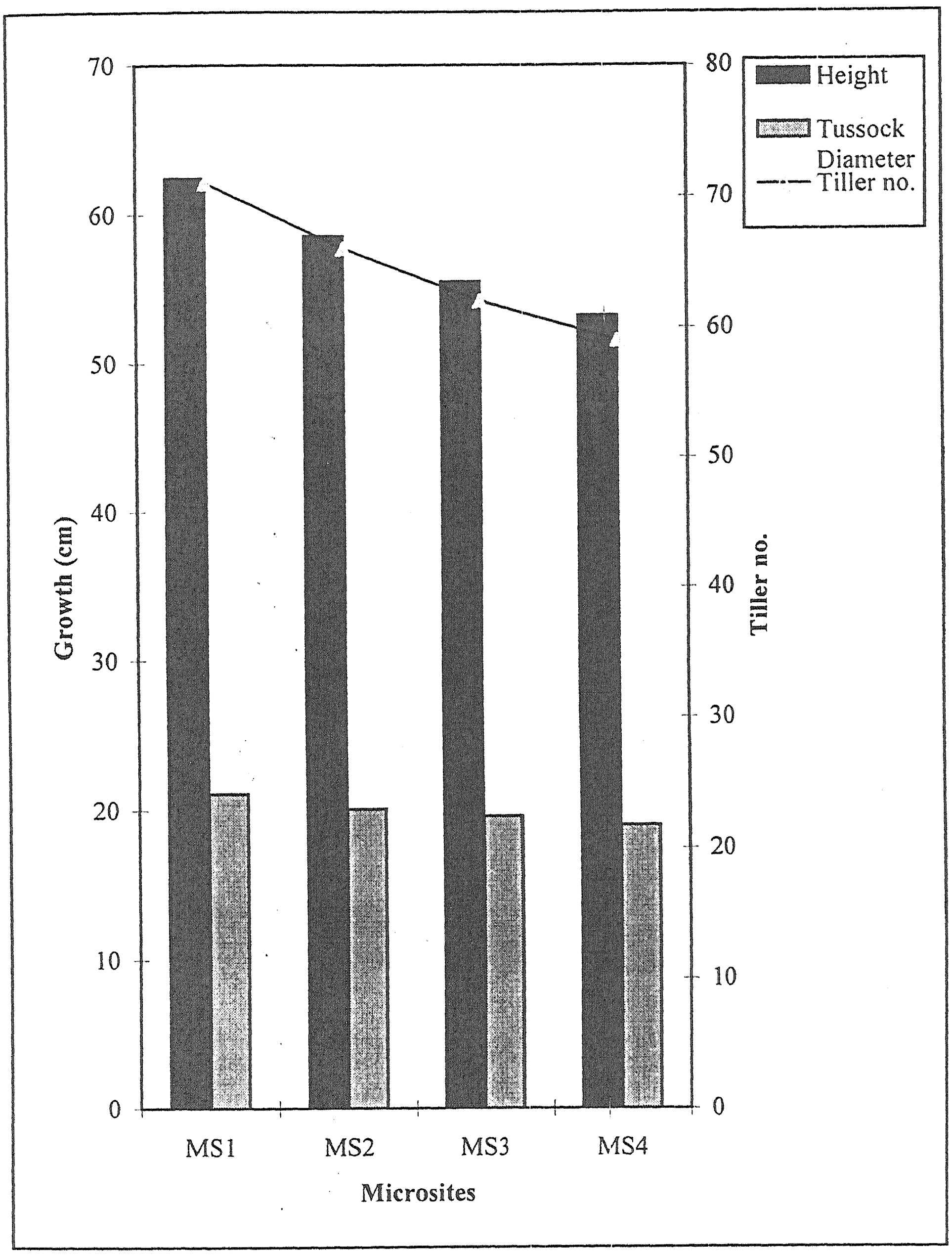


Fig. 10
Average pasture growth characteristics at the four microsites of study (1997-1998).

Table 10
Average growth characteristics of perennial grasses in different microsites of study (1997-1998).

Microsites	Growth characteristics	Grass species				
		(1)	(2)	(3)	(4)	(5)
MS 1	Height (cm)	77.1	67.9	60.5	55.2	51.5
	Tussock diameter (cm)	23.5	22.8	24.6	19.3	15.4
	Tiller No.	95	87	79	51	43
MS 2	Height (cm)	74.5	58.2	57.6	53.2	49.4
	Tussock diameter (cm)	23.2	21.1	24.3	17.5	14.3
	Tiller No.	92	81	73	47	37
MS 3	Height (cm)	73.8	50.4	54.2	52.6	46.6
	Tussock diameter (cm)	22.7	20.6	23.7	17.3	13.8
	Tiller No.	86	74	68	47	36
MS 4	Height (cm)	71.7	47.4	51.4	51.7	44.2
	Tussock diameter (cm)	21.9	20.4	22.9	16.7	13.2
	Tiller No.	79	72	64	44	35

1-*Chrysopogon fulvus*, 2-*Cenchrus ciliaris*, 3-*Heteropogon contortus*, 4-*Sehima nervosum*, 5-*Dicanthium annulatum*

Tussock Diameter

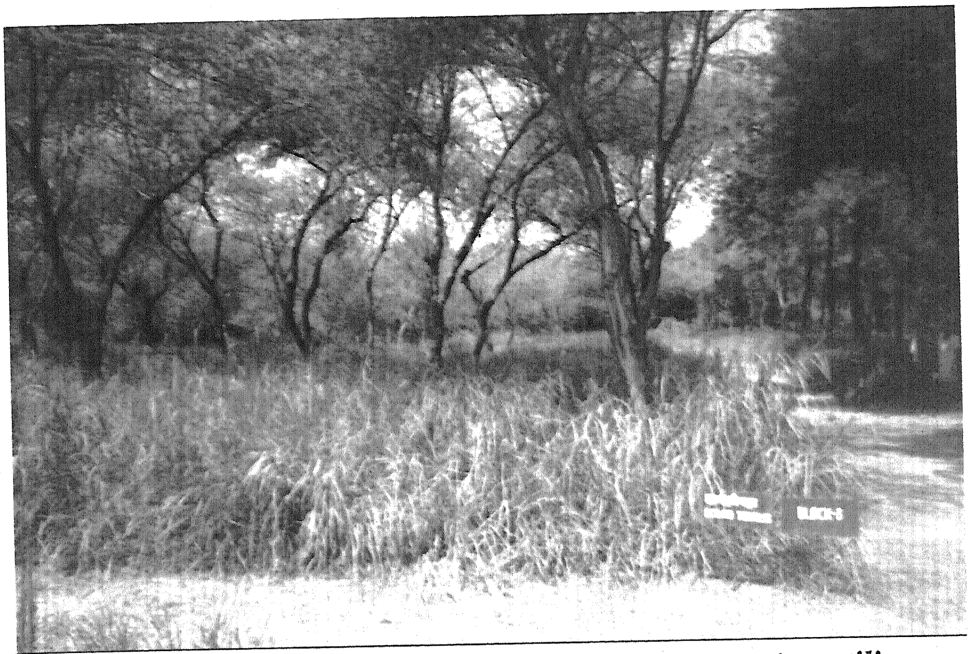
At microsite 1, peak average tussock diameter was exhibited by *Heteropogon contortus* (24.6 cm) followed by *Chrysopogon fulvus* (23.5 cm), *Cenchrus ciliaris* (22.8 cm), *Sehima nervosum* (19.3 cm) and *Dicanthium annulatum* (15.4 cm). At microsite 2, peak average tussock diameter was exhibited by *Heteropogon contortus* (24.3 cm) followed by *Chrysopogon fulvus* (23.2), *Cenchrus ciliaris* (21.1 cm), *Sehima nervosum* (17.5 cm) and *Dicanthium annulatum* (14.3 cm). At microsite 3, peak average tussock diameter was exhibited by *Heteropogon contortus* (23.7 cm) followed by *Chrysopogon fulvus* (22.7 cm), *Cenchrus ciliaris* (20.6 cm), *Sehima nervosum* (17.3 cm) and *Dicanthium annulatum* (13.8 cm). At microsite 4, peak average tussock diameter was exhibited by *Heteropogon contortus* (22.9 cm) followed by *Chrysopogon fulvus* (21.9 cm), *Cenchrus ciliaris* (20.4 cm), *Sehima nervosum* (16.7 cm) and *Dicanthium annulatum* (13.2 cm) (Table 10).

The growth in tussock diameter showed a decreasing trend with increase in canopy density. Such differences between the microsites could be because of the varying microclimatic conditions prevailing on these sites. Similar difference in grass vigour has been reported in some temperate (Smith *et al.*, 1971) and tropical (Trivedi and Gupta, 1994) conditions.

Tiller Number

At microsite 1, highest average tiller number was exhibited by *Chrysopogon fulvus* (95) followed by *Cenchrus ciliaris* (87), *Heteropogon contortus* (79), *Sehima nervosum* (51) and *Dicanthium annulatum* (43). At microsite 2, highest average tiller number was exhibited by *Chrysopogon fulvus* (92) followed by *Cenchrus ciliaris* (81), *Heteropogon contortus* (73), *Sehima nervosum* (47) and *Dicanthium annulatum* (37). At microsite 3, highest average tiller number was exhibited by *Chrysopogon fulvus* (86) followed by *Cenchrus ciliaris* (74), *Heteropogon contortus* (68), *Sehima nervosum* (47) and *Dicanthium*

Plate 2



Pasture growth under a moderately dense stand of *Acacia tortilis*

A view of the *Acacia tortilis* stand after grass harvest during dry season

annulatum (36). At microsite 4, highest average tiller number was exhibited by *Chrysopogon fulvus* (79) followed by *Cenchrus ciliaris* (72) *Heteropogon contortus* (64), *Sehima nervosum* (44) and *Dicanthium annulatum* (35) (Table 10).

The trends in tiller number suggest that microclimatic condition and nutrient status have influence in determining the tillering behaviour of different species. Similar results have been reported by several workers (Gupta and Saxena, 1972; Pathak and Rai, 1990).

Belowground

In silvopastoral systems, distribution of grass roots play an important structural role in stabilizing soil. It is also important from the viewpoint of resource sharing (soil, moisture and nutrients).

The root growth characteristics of the five perennial grasses at the study site are presented in Table 11. Maximum depth of root penetration in soil, mean length of root and mean thickness of root was found in *Chrysopogon fulvus* (35.8 cm, 29.6 cm, 0.74 mm). The root penetration in soil was followed by *Cenchrus ciliaris* (32.4 cm), *Heteropogon contortus* (29.2 cm), *Sehima nervosum* (22.1 cm) and *Dicanthium annulatum* (17.6 cm). The average length and thickness of root was followed by *Heteropogon contortus* (23.8 cm, 0.51 mm), *Cenchrus ciliaris* (22.5 cm, 0.46 mm), *Sehima nervosum* (17.3 cm, 0.39mm) and *Dicanthium annulatum* (11.0cm, 0.24 mm). The mean number of root per plant was recorded in *Cenchrus ciliaris* (527/tussock) followed by *Chrysopogon fulvus* (382/tussock), *Heteropogon contortus* (315/tussock), *Sehima nervosum* (187/tussock) and *Dicanthium annulatum* (89/tussock).

The pattern of root depth and root spread, exhibited by a species mixture on a site, have important ecological implications. Deep rooted species may on one hand be preferred in stabilizing the soil, the comparatively shallow rooted species with more spread may be desirable for maximum utilization of water (Hellemers *et al.*, 1955).

Table 11
Root growth characteristics of five perennial grasses at the study site.

Species	Mean tussock diameter (cm)	Maximum depth of root penetration in soil (cm)	Mean no. of roots /plant	Mean root length (cm)	Mean root thickness (mm)
C. fulvus	22.6	35.8	382	29.6	0.74
C. ciliaris	21.5	32.4	527	22.5	0.46
H. contortus	20.3	29.2	315	23.8	0.51
S. nervosum	16.8	22.1	187	17.3	0.39
D. annulatum	12.1	17.6	89	11.0	0.24

Bist and Kediyal (1989) have studied the root growth characteristics of some grasses in temperate region of Garhwal. Based on root characteristics they concluded that a mixed plantation of *Chrysopogon citrarus* and *Agrostis stolonifera* is useful from soil conservation viewpoint in this region. In this study higher vigour in root growth have been exhibited by *Chrysopogon fulvus, Cenchrus ciliaris* and *Heteropogon contortus* when compared to *Sehima nervosum* and *Dicanthium annulatum*.

Tree Growth

Phenology

Phenology is the study of growth of buds, leaf fall, anthesis, fruiting and seed dispersal in relation to months, seasons or years. These are governed by climatic factors like photoperiod, temperature, moisture and precipitation etc. The phenological study of the ecosystem can help to lay out management practices for a balanced ecosystem function (Leith, 1970). Such studies may also be important from seed collection viewpoint (Mahadevan, 1991).

The period of different phenophase of *Acacia tortilis* at the study site is represented in Table 12. The leaf fall was more evident March onwards and

Table 12
Period of different phenophases of *Acacia tortilis* at the study site (values are on a scale of 1-10) (average 1997-1998).

Phenophase	Months	Scale
Leaf fall	March	9.9
	April	10.0
	May	--
	June	--
Leaf flushing & Leaf formation	April	4.1
	May	5.8
	June	6.4
	July	8.0
	August	8.3
	September	8.7
Budding & Flowering	April	1.8
	May	3.9
	June	10.0
Fruiting	March	--
	April	--
	May	4.8
	June	10.0

continued up to June. This appears to be a sort of xerophytic adaptation to protect itself from rigours of dry season. This character is also seen in some other deciduous species like *Tamarix articulata*, *Phyllanthus emblica* and *Casuarina equisitifolia* (Mac Dicken, 1994).

Flushing and leaf formation occurred in April-May. However, leaf formation continued up to September. The formation of leaf was at its peak during June/July-September. The leaf replacement strategies during summer months appear to minimize stress by leaf fall at such period and maximize photosynthetic activity during wet warm season of the year through flushing (Njoku, 1963; Shukla and Ramakrishnan, 1982).

The buds and flowers appeared in April and continued up to May. Pods developed rapidly and reached to full size by June end.

Aboveground

The growth attained by trees is an important attribute of silvopastoral system as it is an indication of its role in supplying timber, firewood and fodder etc. besides determining the optimum rotation period of the system. Similarly, canopy spread has significant implications in determining the microclimate beneath it, which in turn may affect the productivity of understorey species (Deb Roy, 1988 a; 1988 b; Singh *et al.*, 1992; 1993; 1994).

The growth of *Acacia tortilis* was studied at the three silvopasture microsites. The results are being presented in Tables 13 and 14.

Height

The average height of trees at different microsites decreased from 7.14 to 5.46 m with the increase in tree density. Hence, mean annual increment also decreased from 0.51 to 0.39 m with the increase in tree density at the different microsites. It shows that these trees have almost attained a plateau in height growth by this time and further rate of increase is extremely slow. Similar trend of

Table 13
Mean annual increment in growth parameters in *Acacia tortilis* in silvopastoral systems (at 14th year).

Density	Height (m)	Canopy (m)	cd (cm)	dbh (cm)
MS 2	0.51	0.19	1.25	1.08
MS 3	0.40	0.16	0.90	0.74
MS 4	0.39	0.13	0.89	0.79
CD (>0.05)	NS	NS	0.22	0.27

Table 14
Average growth characteristics of *Acacia tortilis* (1997-1998).

Microsites	Height (m)	Canopy (m)	cd (cm)	dbh (cm)
MS 2	7.14	2.66	17.50	15.12
MS 3	5.60	2.24	12.60	10.36
MS 4	5.46	1.84	12.46	11.06

height growth in respect of several forest trees has been reported by Troup (1921, reprint 1986).

Canopy spread

The average spread in canopy decreased from 2.66 m at microsite 2 to 1.84 m at microsite 4. Hence, mean annual increment also decreased from 0.19 to 0.13 m. However, the differences in between different microsites were not significant statistically.

The growth in canopy has been related with number of trees per ha, lesser number indicating higher growth. Such a trend has been reported from 20^+ year old trees of *Acacia senegal*, *Albizia lebbek*, *Prosopis cineraria* and *Tecomella undulata* in arid conditions of Rajasthan (Muthana *et al.*, 1984).

Diameter

The average growth in diameter (cd/dbh) decreased from (17.50/15.12 to 12.46/10.36 cm). Hence, mean annual increment in cd/dbh also decreased from 1.25/1.08 cm to 0.89/0.74 cm. The diameter decreased consistently with the increase in tree density. Thus, like canopy spread the growth in diameter was found related to the number of trees per ha. Similar trends of diameter growth from mature trees of *Acacia senegal, Albizia lebbek*, *Prosopis cineraria* and *Tecomella undulata* has been reported by Muthana *et al.* (1984).

Belowground

Root growth studies in silvopastoral systems are of great significance to manage tree and grass component (Prajapati *et al.*, 1971; Dhyani *et al.*, 1990; Patil *et al.*, 1994).

The root growth characteristics of *Acacia tortilis* at the study site are presented in Table 15. The length of tap root varied from 0.7 to 1.3 m in different trees of *Acacia tortilis*. The number of major secondary roots varied from 13 to

19. This compares well with the root system of similar aged trees of *Prosopis cinerarea, Acacia senegal* and *Albizia lebbek* growing in arid regions of Rajasthan. This is based on the data reported by Muthana *et al.* (1984). The diameter of tap root varied from 17.6 to 27.4 cm, 7.9 to 10.2 cm and 0.70 to 1.2 cm at the base, center and tip zones, respectively. This indicates that bulk of roots are confined within 1 m of soil depth.

Table 15
Root growth characteristics of *Acacia tortilis* at the study site.

Growth characteristics	Range	Average
Tree height (m)	5.1 – 7.3	6.0
Tree dbh (cm)	9.9 – 16.1	12.4
Length of tap root (m)	0.7 – 1.3	1.0
Number of major secondary roots	13 – 19	16
Diameter of tap root (cm)		
Base	17.6 – 27.4	21.6
Centre	7.9 – 10.2	8.3
Tip	0.7 – 1.2	0.8

Dhyani *et al.* (1990) reported similar observation on several young tree species *viz.*, *Grewia optiva*, *Bauhinia purpurea*, *Eucalyptus tereticornis*, *Leucaena leucocephala* and *Ougeinia oojeinensis* in Doon vally. However, they did not notice any significant difference in soil moisture under tree canopy cover and in open. In this present study, soil moisture was found to be higher under trees as compared to open situation as a result of favourable microclimate under trees. Thus, *Acacia tortilis* appears to be a desirable tree for agroforestry/silvopastoral systems where tree and pasture can fed from different depth (Berendse, 1979).

PART III

SYSTEM PRODUCTIVITY

Assessmemt of system productivity in silvopastoral systems are of great significance for proper management and utilization of various products *viz.*, timber, firewood and fodder. The understorey, consisting of herbaceous species, constitutes the major source of fodder during July/August to November/December in semi-arid regions. The pasture species play a key role in any improvement and more intensive system of land utilization. According to Pandeya (1988) full use of renewal pasture resources and conserving them to the region of negative feed back, alone, will lead to plan maintenance of homeostatic plateau for lasting economy.

Ground Vegetation

In this study, for the purpose of biomass estimation the ground vegetation was grouped into grasses (both perennial and annual) and leguminous forbs/weeds. Table 16 presents data on understorey biomass production at different microsites during 1997 and 1998. Significantly higher level of aboveground biomass was recorded in open situation when compared to the canopy situations in both the years. During 1998 the production level was higher when compared to 1997. This may be attributed on account of two reasons; (i) higher rainfall receipts during 1998 and (ii) heavy lopping practiced on these stands during 1997. Among different canopy situations significant difference in aboveground yield was recorded in between light and dense canopy situation only. As expected, highest reduction in aboveground biomass production was recorded in dense canopy situation (22.7 %) followed by medium canopy situation (12.4 %) and light canopy situation (8.6 %).

The proportion of leguminous forbs/weeds was higher under canopy situations (9.7 to 12.3 %) when compared to the open situation (10.4 %) (Table 16). Among canopy situations highest proportion of leguminous

Table 16
Understorey biomass production (DM t/ha) at different microsites of study (1997 and 1998).

Parameter	Year	MS1	MS2	Silvopasture System MS3	MS4	CD (<0.05)
AG Biomass	1	3.37 (9.3)	3.13 (9.4)	2.96 (10.4)	2.49 (11.4)	0.42
	2	3.86 (11.5)	3.47 (10.1)	3.36 (11.7)	3.13 (13.2)	0.27
	Mean	3.61 (10.4)	3.30 (9.7)	3.16 (11.0)	2.81 (12.3)	--
BG Biomass	1	1.16	0.93	0.79	0.70	0.17
	2	1.27	1.07	0.83	0.82	0.21
	Mean	1.21	1.00	0.81	0.76	--
Total Biomass	1	4.53	4.06	3.75	3.19	0.50
	2	5.13	4.54	4.19	3.95	0.39
	Mean	4.83	4.30	3.97	3.57	--

(NOTE: Value in parenthesis indicate percent biomass on dry matter basis contributed by the weeds)

forbs/weeds was recorded in dense situation (12.3 %) followed by medium situation (11.0 %) and light situation (9.7 %). This could be attributed to the interaction between modified microclimatic condition and edaphic condition prevailing at a particular microsite.

Like the aboveground biomass production, significantly higher level of belowground biomass production was recorded in open situation when compared to the canopy situations in both the years. During 1998 the production level was higher when compared to 1997. This may be attributed on account of higher rainfall receipt during 1998 and more opening of the canopy as a result of heavy lopping practiced on these stands during 1997. Among different canopy situations significant difference in below ground yield was recorded in between light and dense canopy situations only. Highest reduction in belowground biomass production was recorded in dense canopy situation (37.2 %) followed by medium canopy situation (33.0 %) and light canopy situation (17.3 %). The level of reduction under canopy situations was higher in case of belowground biomass when compared to the aboveground biomass (Table. 16).

The total biomass production from ground vegetation was calculated (Table 16). Significantly higher level of total biomass recorded in open situation when compared to the canopy situations in both the years. Consistently, higher level of total biomass production was maintained during 1998 when compared to 1997. The reasons for this have already been mention in the above paragraphs. Among different canopy situation significance difference in total yield was observed between light and dense canopy during 1997. However, during 1998 the difference was not significant. Highest reduction in total yield was recorded in dense canopy situation (26.1 %) followed by medium canopy situation (17.8 %) and light canopy situation (11.0 %). The higher proportion of below ground biomass (25 %) was recorded in open situation when compared to the canopy situation (0.21-0.23 %).

The productivity of grasses is an important attribute of carrying capacity of rangelands as it has important implication in forage supply. The biomass in grasses is more concentrated at base giving the appearance of an upright pyramid, the extent of which depends on the height of plants (Singh and Yadav, 1974). The layer structure of a multi-layer pasture community has several advantages. For example, each quantum of incident light has great probability of being intercepted and used in a multi-layered canopy as compared to single layer canopy (Pandeya, 1974). Such an arrangement has important implication in prolonging forage availability (Singh, 1968).

Although, density of individual species is a good expression of their relative abundance, it is often a not related with the biomass of the species. However, total vegetation density (number of tiller/m^2) of grazing lands has been found to be positively correlated with total community above ground biomass (Singh and Yadav, 1972). In this study the yield at different microsites was found to be related with total density of ground vegetation. For example, highest plant density in open situation (417/m^2) is related with peak average above ground biomass production (3.61 DM t/ha). Also, density shared by perennial grasses was higher in open situation (80.8 %) when compared to the canopy situation (62.8-71.6 %). These growth attributes are infact reflected in their biomass contribution.

Similar results have been obtained by Mall and Billore (1974), between vegetation density and net aerial primary production for a *Sehima* grazing land near Ratlam in Central India. Singh (1990) found relationship between plant stand and ground cover and dry matter production in some promising grasses *viz.*, *Pennisetum purpureum*, *P. purpureum* - *P. typhoides* - IGFRI 5 and *Panicum maxicum* cultivar Cv Makueni. Kateva and Tiagi (1991) reported similar results from three grazing lands of Udaipur District each dominated by an important grass species *viz.*, *Sehima nervosum*, *Heteropogon contortus* and *Apluda mutica*. In Central Himalaya, species composition and density determined herbage yield at different sites under *Chir* forest (Chaturvedi and Saxena, 1992).

Grass productivity under silvopastoral systems has been studied by several worker. Ramakrishan *et al.* (1981) reported poor yield of *Cenchrus ciliaris* under mature and unlopped trees of *Acacia tortilis*, as compared to open situation at Jodhpur. The low energy availability beneath the canopy was identified as the cause for poor performance of *Cenchrus ciliaris*. However, Deb Roy *et al.* (1980) found marginal difference in forage production of *Cenchrus ciliaris* and *Cenchrus setigerus* grown in association with medium sized *Acacia tortilis/Leucaena leucocephala* trees when compared to open situation at Jhansi.

Hazra and Patil (1986) reported forage yield of grasses under different moderate sized trees *viz.*, *Albizia lebbek*, *Albizia procera*, *Leucaena leucocephala* and *Acacia tortilis* and in open situation at Jhansi. Dry forage yield marginally decreased under *Acacia tortilis* (7.9 %), *Leucaena leucocephala* (14.4 %) and *Albizia procera* (6.0 %) canopies. They identified microclimatic variation as the main reason for such a difference. Deb Roy (1988) reported higher forage production from a mixture of *Sehima nervosum* + *Chrysopogon fulvus* (3.76 DM t/ha) compared to that of *Cenchrus ciliaris* alone (3.30 DM t/ha) under moderate canopy of *Hardwickia binata*. The production level from the same pasture was lower under moderate canopy of *Albizia amara* (3.3 DM t/ha) and *Acacia tortilis* (3.1 DM t/ha), respectively. Forage production was affected adversely with the increase in tree density in both the species.

Hazra and Tripathi (1989) studied performance of two, oat genotype under moderate sized tree canopy of *Albizia lebbek*, *Hardwickia binata*, *Acacia nilotica* and *Melia azadirach* at Jhansi. The genotype OL 189 was found be superior for agroforestry system. The average oat yield was 95 per cent under *Albizia lebbek*, 90 per cent under *Hardwickia binata*, 88 per cent under *Acacia nilotica* and 74 per cent under *Melia azadirach* as compared to open plot yield.

Prasad (1990) studied grass productivity under 6-10 year old plantation of twelve different tree species *viz.*, *Acacia campylacantha*, *Albizia procera*, *Albizia lebbek*, *Anogeissus pendula*, *Cassia siamen*, *Cleistanthus callinus*, *Dalbergia*

sissoo, *Hardwickia binata*, *Holoptelia integrifolia*, *Eucalyptus tereticornis*, *Pongammia pinnata*, *Terminalia belenica* at Jodhpur. The results indicated that although some species had inhibitory effect on grass production, the average grass yield level of 3-4 DM t/ha from these plantations was not insignificant as this is obtained without extra cost.

Several reports pertaining to root and shoot proportion of grass species are available. Bray (1963) found that root and shoot proportion of range and pasture grasses varied with species. Soil fertility levels, climatic conditions and variation in species diversity were identified as the other major reasons. Pandit (1984) reported wide variation in belowground/aboveground ratio of *Dicanthium annulatum* in different months from 0.27 (September) to 2.67 (June) in grazing lands at Bhavnagar. However, Chaturvedi *et al.* (1988) reported peak grass biomass (both aboveground and belowground) production during September under *Pinus roxburghii* forests in Kumaun. The average BG/AG ratio was found to be 0.37.

Bist and Kediyal (1989) studied BG/AG ratio in grass species like *Cymbopogon citratus*, *Vetiveria zizanioides*, *Saccharum maranga* and *Egrostis stolonifera* at different elevation in Central Himalaya. The BG/AG ratio varied widely from 0.16 to 0.50.

As in this study, Verma and Rao (1988) reported higher AG biomass, as compared to BG biomass at grassland ecosystem, on marginal land of Banthara (near Lucknow). However, Pandya and Sidha (1989) reported higher belowground biomass as compared to aboveground biomass in grazing lands at Kutch. They concluded that photosynthetic input in excess of metabolic requirement of aboveground live was probably diverted towards belowground biomass. Verma and Rao (1988) reported no definite trend of seasonal variation in BG/AG ratio in any of their study site. However, BG biomass were reported to be effected due to rainfall and soil fertility level, especially the sodium content.

There existed a strong correlation with above ground live biomass, total community biomass and aerial net primary productivity.

The results obtained in this study on the aspect *viz.*, yield from ground vegetation at different microsite, proportion of belowground biomass etc. relate to most of the above findings. Thus biomass from ground vegetation in silvopastoral systems is largely determined by microclimate, species diversity, density and vigour in a multifactional fashion.

Standing Tree

Tree productivity is usually estimated in terms of merchantable log volume in traditional forestry. However, in silvopasture where a multiplicity of products *viz.*, foliage, branches, small and large size timber material etc. are required; estimation of biomass accumulated in different tree components is important (Applegate *et al.*, 1988).

In this study, standing tree biomass of *Acacia tortilis* was estimated for the three microsites based on representative tree fellings during 1997 and 1998. Table 17 presents the data on standing tree biomass accumulation in different parts of *Acacia tortilis* (13-14 year age) at different microsites.

At all the microsites, generally, higher biomass was recorded during 1998 (after 14 year growth) when compared to 1997 (after 13 year growth). This may be attributed to higher growth attained by the trees during 1998. Highest mean total biomass was recorded at microsite 4 (93.3 DM t/ha) followed by microsite 3 (82.8 DM t/ha) and microsite 2 (71.2 DM t/ha). The proportion of aerial biomass to total biomass was highest at microsite 4 (85.0 %) closely followed by microsite 3 (83.8 %) and microsite 2 (83.2 %).

Highest proportion of bole to total aerial production was recorded at microsite 4 (22.6 %) followed by microsite 2 (22.5 %) and microsite 3 (20.0 %). The proportion of branch was highest in microsite 3 (77.0 %) followed by microsite 4 (74.3 %) and microsite 2 (73.9 %). Highest proportion of leaf was

recorded in microsite 4 (0.6 %) followed by microsite 3 (0.5 %) and microsite 2 (0.4 %). Highest proportion of pod was recorded in microsite 2 (3.2 %) closely followed by microsite 3 and microsite 4 (2.5 %). The proportion of belowground biomass to aboveground biomass was highest in microsite 2 (16.8 %) followed by microsite 3 (16.2 %) and microsite 4 (15.0 %).

Table 17
Standing tree biomass (DM t/ha) from trees of *Acacia tortilis* in silvopastoral system (1997 and 1998).

Microsite	Year	Standing Tree Biomass					
		Bole	Branch	Leaf	Pod	Root	Total
MS 2	1	13.20	42.24	0.24	1.68	11.64	69.0
	2	13.50	45.25	0.30	2.02	12.25	73.3
	Mean	13.35	43.74	0.27	1.85	11.94	71.2
MS 3	1	14.40	52.56	0.36	1.80	13.60	82.7
	2	13.25	54.25	0.42	1.82	13.25	83.0
	Mean	13.82	53.40	0.39	1.81	13.42	82.8
MS 4	1	16.80	57.12	0.50	1.89	13.87	90.2
	2	19.00	60.75	0.50	2.10	14.00	96.4
	Mean	17.90	58.93	0.50	1.99	13.93	93.3

Detailed biomass studies on many trees are available from different studies (Gurumurthy *et al.*, 1984; Gurumurthy *et al.*, 1984 a; Verma and Mishra, 1986; Chandrashekharaiah and Prabhakar, 1987; Ambasht, 1988; Singh, 1988; Kushalappa, 1988; Deb Roy, 1988 a; Deb Roy, 1988 b; Pal and Raturi, 1989; Srivastava, 1994; Roy, 1995). However, on account of different soil and climatic conditions, plantation density and plantation age, many of these studies are not

comparable with the present study. However, if a comparision is made with species like *Acacia tortilis*, *Hardwickia binata* and *Albizia amara* on similar sites (Pathak *et al.*, 1988; Khan *et al.*, 1993; Singh and Gupta, 1993), the growth attained by *Acacia tortilis* was found to be better.

The diameter, especially the diameter at breast height (dbh) has been found to be most appropriate in determining biomass and timber volume in species like *Acacia tortilis, Hardwickia binata, Leucaena leucocephala* and *Albizia amara* (Pathak *et al.*, 1988; Khan *et al.*, 1993; Roy, 1995). Thus by simply measuring dbh and estimation about tree productivity in case of *Acacia tortilis* may be made for planning purposes.

The BG/AG ratio based on dry matter basis was found to vary between 0.17 to 0.20 in case of *Acacia tortilis* trees at this site during February/March. The BG/AG ratio in trees varies with species, age, plantation density, soil fertility, climatic conditions and species diversity (Michael, 1986).

Kaul *et al.* (1983) reported BG/AG ratio of 0.027 from 8 years old *Populus deltoides* in *Tarai* region of Uttar Pradesh. Murphey and Lugo (1986) found a ratio of 0.50 from a sub tropical forest (stem density 12000/ha) in Puerto Rico. Casrellanos *et al.* (1991) reported a ratio of 0.42 from a dry deciduous forest (4700 tree/ha with basal area dbh of 23 m^2/ha) in Mexico. Dhyani *et al.* (1990) reported a BG/AG ratio of 0.37, 0.40 and 0.41 on young and moderately spaced trees of *Leucaena leucocephala*, *Eucalyptus tereticornis* and *Grewia optiva*, respectively in Doon Velly. Singh and Gupta (1993) reported a ratio of 0.28 to 0.32 from 19 year old *Hardwickia binata* on *Bhata* soils near Raipur.

Thus the BG/AG ratio recorded in this study is on a lower side, indicating more biomass allocation towards aerial parts.

Lopping of Trees

Top feed are best utilized either through browsing by livestock or by providing fresh lopped fodder to the animals. Freshly lopped leaves are also

stored as dried leaves or silage. The existing practice of excessive and indiscriminate lopping of trees has resulted in the depletion of valuable fodder resources. Judicious lopping of fodder trees in silvopasture systems is crucial for maintaining pasture productivity and providing fodder and firewood during lean periods (Singh, 1982; Roy, 1992).

In this study, biomass obtained from *Acacia tortilis* through lopping was estimated during 1997 and 1998. Table 18 presents the data on lopped tree biomass *viz.*, branch and leaf at different microsites. Highest total lopped biomass was recorded at MS 4 (0.47 DM t/ha) followed by MS 3 (0.26 DM t/ha) and MS 2 (0.15 DM t/ha). The proportion of mean leaf production was highest at MS 4 (38.3 %) followed by MS 3 (30.8 %) and MS 2 (26.7 %). Higher level of lopped biomass was obtained during 1998 when compared to 1997. This may be attributed on account of two reasons; (i) heavy lopping practiced on these stand to open up the canopy during 1997 and (ii) higher rainfall receipt during 1998.

The results indicate that through judicious lopping management additional forage (0.04 – 0.18 DM t/ha) and firewood (0.11 – 0.29 DM t/ha) yields could be obtained from mature *Acacia tortilis* stands. This management has also important implication in increasing the pasture productivity as a result of opening up of the canopy. This is evident from the results presented in Table 18.

The published literature on lopping management of fodder trees is scanty. Most of the information on such aspects is available for *Prosopis cinerea* where annual loppping up to 2/3 of the canopy has been recommended (Bhimaya *et al.*, 1964; Ganguly *et al.*, 1964; Srivatava, 1978; Ghosh, 1980). Some information is also available in respect of *Quercus* (Gorrie, 1937); *Albizia procera* (Laurie, 1945; Roy, 1991); *Acacia nilotica* (Deb Roy *et al.*, 1982); *Acacia tortilis, Albizia amara, Hardwickia binata, Albizia lebbek, Dichrostachys cineraria* (Roy, 1991).

The biomass obtained as a result of lopping *Albizia amara* trees is on a higher side when compared to lopped biomass obtained from other species *viz.*, *Acacia tortilis, Albizia lebbek, Albizia procera, Dichrostachys cineria* on similar

site (Roy, 1991; Singh *et al.*, 1992; Pathak and Roy, 1994). This could be attributed due to high leafy proportion and very high regeneration ability.

Table 18
Lopped tree biomass (DM t/ha) from trees of *Acacia tortilis* in silvopastoral systems (1997 and 1998).

Microsite	Year	Lopped Biomass		
		Branch	Leaf	Total
MS 2	1	0.06	0.02	0.08
	2	0.16	0.07	0.23
	Mean	0.11	0.04	0.15
MS 3	1	0.09	0.03	0.12
	2	0.27	0.13	0.40
	Mean	0.18	0.08	0.26
MS 4	1	0.16	0.07	0.23
	2	0.43	0.29	0.72
	Mean	0.29	0.18	0.47

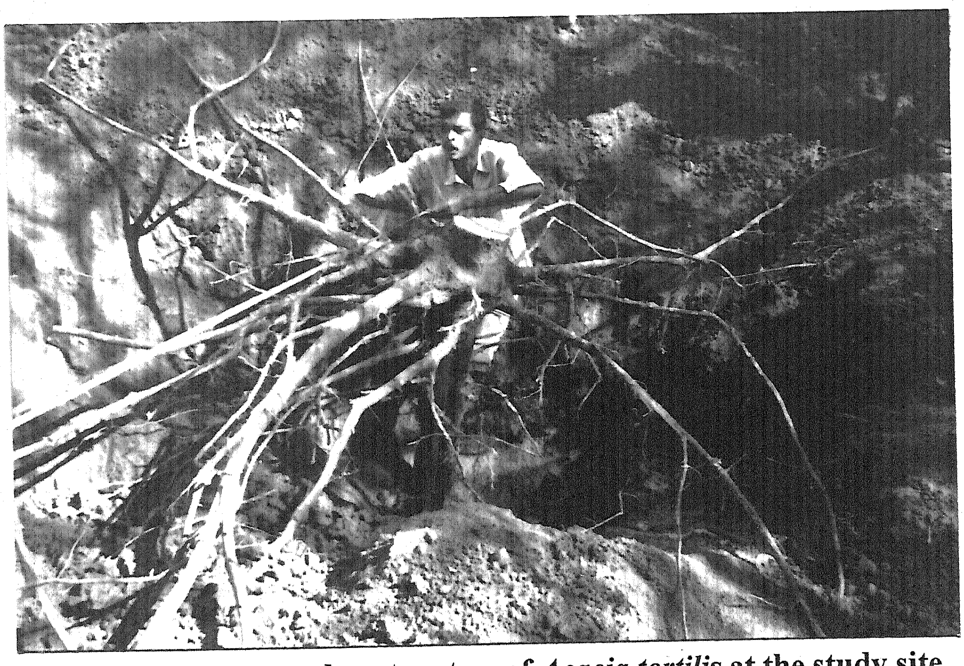
Total System Productivity

Although work on silvopasture was initiated in 1960s, the earlier information was generated only in the piece meal. So, comparatively less information is available on evaluation on total system productivity in given rotation (Pathak and Roy, 1994).

In this study, an attempt was made to project aboveground, belowground and total biomass of different microsites based on the data set generated during 1997 and 1998. Table 19 presents the data on aboveground biomass production at the four microsites.

Plate 3

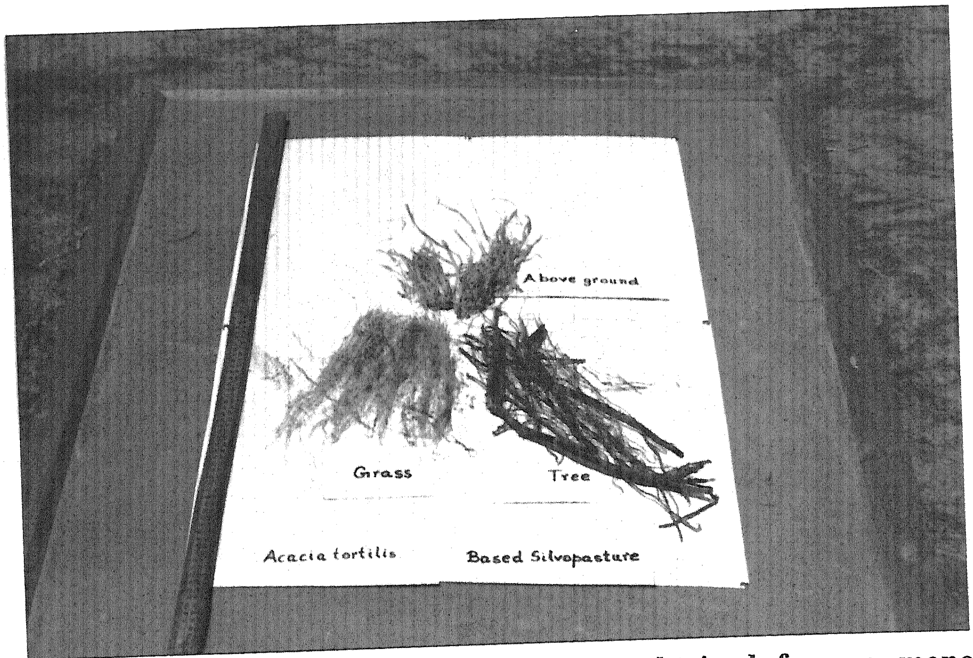
Lopping of *Acacia tortilis* at the study site



A view of the excavated root system of *Acacia tortilis* at the study site

Plate 4

A view of the excavated monolith for estimating belowground biomass of the understory



The above and belowground components obtained from a monolith (in dry season)

In open situation (without tree i.e. MS 1), average forage production of 3.61 DM t/ha/yr was recorded. All this forage came from the ground vegetation during July to November/December. The forage supply (pasture component) decreased in silvopasture with increase in tree density. This reduction was in the range of 8.6 per cent to 22.2 per cent. However, such systems yielded top feeds during January to April. The availability of top feed increased from 0.06 DM t/ha/yr to 0.21 DM t/ha/yr with increase in tree density. Thus effective decrease in forage supply under silvopasture was only in the range of 6.9 per cent to 16.3 per cent (Table 19).

However, the marginal decrease in forage supply under silvopasture has been well compensated by the other tree products *viz*., firewood (3.35 – 4.65 DM t/ha/yr), minor timber (1.00 – 1.32 DM t/ha/yr), pod and seed (0.13 – 0.15 DM t/ha/yr). Thus aboveground productivity under silvopastures increased from 2.17 to 2.53 times when compared to only pasture land use system (Table 19).

Table 19
Total aboveground biomass production (DM t/ha/yr) at the different microsites of study (1997-1998).

Microsite	Forage	Topfeed	Firewood	Minor Timber	Pod & Seed	Total
MS 1	3.61	--	--	--	--	3.61
MS 2	3.30	0.06	3.35	1.00	0.14	7.85
MS 3	3.16	0.10	4.13	1.02	0.13	8.54
MS 4	2.81	0.21	4.65	1.32	0.15	9.14

The trend of aerial productivity from mature *Acacia tortilis* (> 13 year) based silvopastures at different microsites is presented in Fig. 11. The proportion of tree products increased from 58 per cent to 69 per cent, with the increase in tree

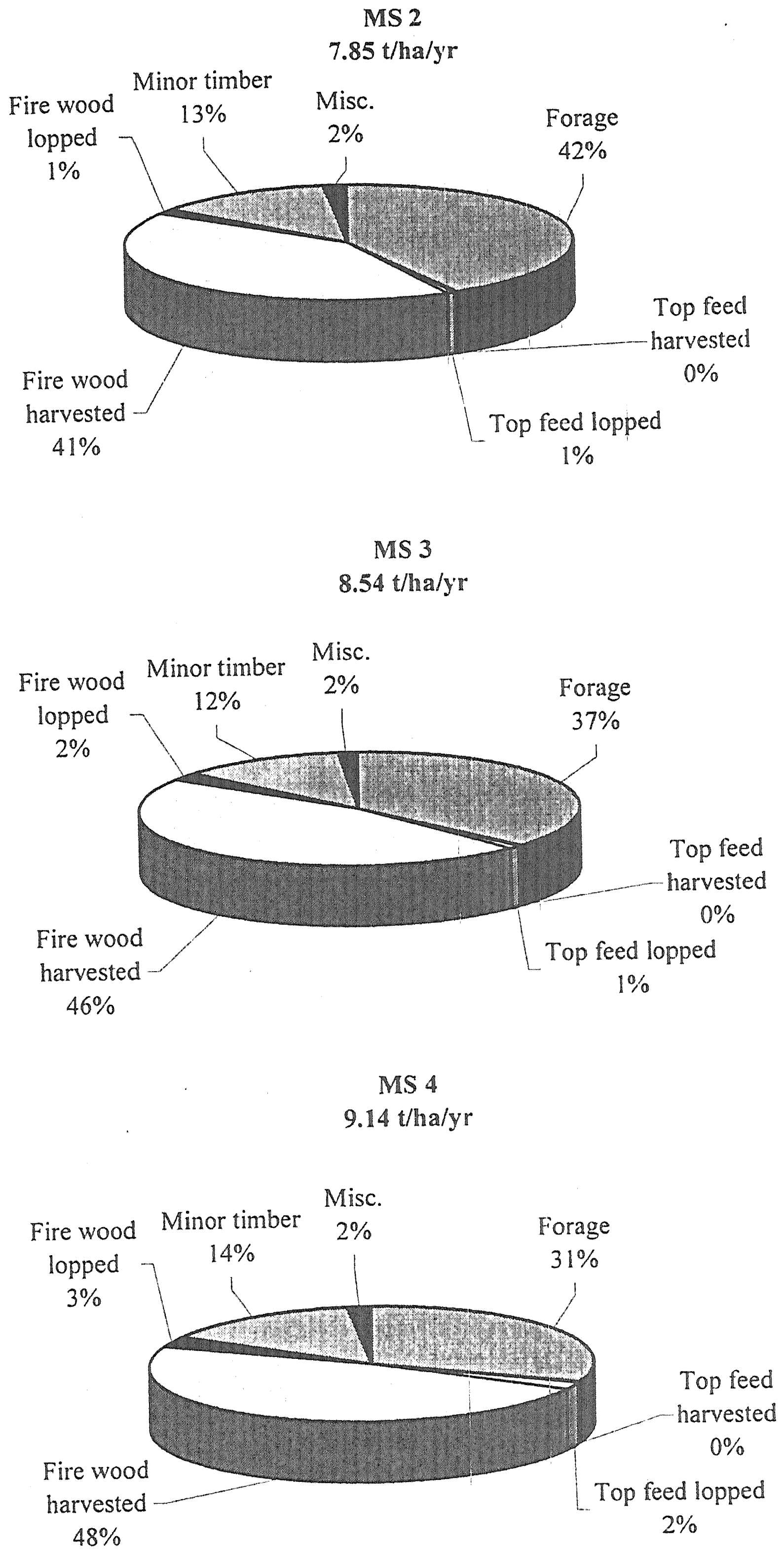


Fig. 11
Aerial productivity (DM t/ha/yr) from *Acacia tortilis* (> 13 year) based silvopastures at different microsites.

stocking rate per ha. On final harvest, proportion of wood (minor timber + firewood) increased from 44 to 62 per cent with the increase in tree density.

Lopping on an annual basis maintained higher top feed and firewood supply with the increase in tree density. The proportion of top feed supplies increased from 1 per cent to 2 per cent and firewood supplies from 1 per cent to 3 per cent.

Some studies on assessment of total silvopasture system productivity on comparatively shorter rotation (10-12 years) are available. These studies indicated aerial productivity in the range of 6-10 DM t/ha/yr depending on the site characteristics (Singh *et al.*, 1990; Singh *et al.* 1992; 1993; 1994; Singh and Roy, 1993; Pathak and Roy, 1994; Singh and Roy, 1998; Mal and Roy, 1999). In most of the studies, proportion of forage from pastures varied from 40 to 45 per cent. However, in this study, proportion of forage was quit low. This may be attributed to: (i) densely spreading tree canopy at the maturity; (ii) computation were made from the data recorded during canopy closure stage only. Apart from this factors, aerial system productivity matches with the earlier data. However, as this productivity has been calculated as on a much longer rotation the overall bio productivity of *Acacia tortilis* based systems appears to be quite high.

Table 20 presents data on belowground biomass productivity at the four microsites. The belowground biomass varied from 1.21 to 1.88 DM t/ha/yr. There was an increase of 55 per cent in belowground biomass at canopy situation (MS 2-MS 4) when compared with that of open situation (MS 1), but there was not much difference in belowground biomass production at canopy situation (MS 2-MS 4), only a marginal decrease of 4 per cent at MS 3 and 5 per cent at MS 4 was recorded.

Table 21 presents data on total biomass productivity (aboveground + belowground) at the four microsites. Highest total system productivity was recorded at MS 4 (10.93 DM t/ha/yr) followed by MS 3 (10.34 DM t/ha/yr), MS 2 (9.73 DM t/ha/yr) and MS 1 (4.82 DM t/ha/yr). Thus total system productivity

under silvopastures increased from 2.02 to 2.27 times when compared to only pasture land use system.

A few composite samples were drawn at the time of grass/top feed harvest. Major attributes of forage quality *viz.*, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) were got analysed through Central Analytical Laboratory of IGFRI.

Table 22 presents data on average forage quality of pasture species and top feed. The top feed maintained much higher level of CP (11.8 %) when compared to the pasture component (3.9 %). The NDF and ADF values were higher (63.6, 47.0) in the pasture component when compared to top feed (39.4, 33.9).

A lot of variability in average forage quality attributes like CP, NDF and ADF has been reported in many studies. Such variations are mainly attributed to the effect of seasonality and site factors (Singh, 1982; Minson, 1990; Norton and Poppi, 1995). Also, these studies were conducted in isolation, only component wise.

In one study were chemical compositions of forage was studied in open and fenced plot, CP during September was more in fenced plots when compared to open. However, during October in control situation the order was reverse but fenced plots having trees had more CP (Singh *et al.*, 1992). Although such studies were not undertaken in the present investigation, consistently higher average CP level in top feeds indicate improvement in forage quality in silvopastures (Singh *et al.*, 1993; 1994).

Table 20
Total belowground biomass production (DM t/ha/yr) at the different microsites of study (1997-1998).

Microsite	Pasture	Tree	Total
MS 1	1.21	--	1.21
MS 2	1.00	0.88	1.88
MS 3	0.81	0.99	1.80
MS 4	0.76	1.03	1.79

Table 21
Total productivity (DM t/ha/yr) at the different microsites of study (1997-1998).

Microsite	Aboveground	Belowground	Total
MS 1	3.61	1.21	4.82
MS 2	7.85	1.88	9.73
MS 3	8.54	1.80	10.34
MS 4	9.14	1.79	10.93

Table 22
Average forage quality (%) of different components of silvopastoral systems.

Attributes	Pasture	Tree leaf fodder
CP	3.9	11.8
NDF	63.6	39.4
ADF	47.0	33.9

PART IV

NUTRIENT TURN OVER

The terrestrial ecosystem productivity is regulated by a number of environmental factors including radiation, temperature, water and availability of nutrients. The availability of nutrients is also affected by these environmental factors and in most forests productivity is directly related to nutrient availability and uptake (Binkley, 1986).

The nutrients are elements required to complete plants life cycle. About 95 per cent of plants biomass (as dry weight basis) is composed of Carbon, Oxygen and Hydrogen. The remaining elements are classified as macro nutrients (nitrogen, sulphur, potassium, phosphorus, calcium and magnesium) and micro nutrients (manganese, iron, chlorine, copper, zinc, molybdenum and boron). Each of these elements has unique pattern of sources, transformation and availability to plants under varying environmental condition (Mengel and Kirkby, 1982).

Since, carbon, oxygen and hydrogen are so abundant that they are not usually included in discussion on nutrient cycle. Nitrogen most commonly limits productivity of terrestrial ecosystems. Besides nitrogen, phosphorus (being part of energy transformation), potassium (activating many enzymes), calcium (in connecting organic molecules) are also important in most of such ecosystems (Bruijnzel, 1991).

In this study, nutrient turnover under silvopastures was assessed at all the three microsites. Since, grasses were utilized through cut and carry system on an annual basis, a matching study at microsite 1 could not be undertaken. The results obtained from studies related to assessment of litter production (from trees); nutrient analysis in litter and standing vegetation; pattern of nutrient lockup; recyclable nutrients and litter decomposition at different microsites are being discussed in this part.

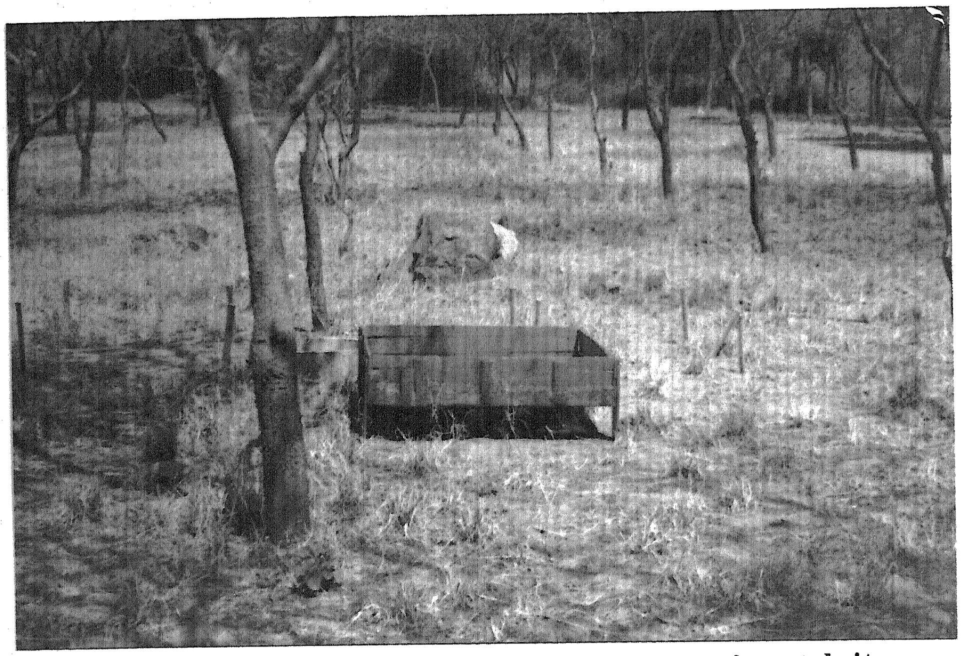
Litter Production

In tree based ecosystem like silvopastoral system, the interaction and sequential processes of litter fall, its decomposition and subsequent mineralization of nutrient play a key role in sustaining productivity. The rate of litter production, decomposition and mineralization are complex processes and depend upon various factors of physico-chemical environment and the quantity and quality of organic residues/litter. The amount and pattern of leaf fall varies with the types of tree species, tree growth, age, density and canopy characteristics. An understanding of litter fall dynamics has important implication in relation to nutrient cycling and in assessment of potential role of trees in ameliorating soil under agroforestry/silvopastures (Golley, 1978; Malik and Prakash, 1993; George and Mohan Kumar, 1998).

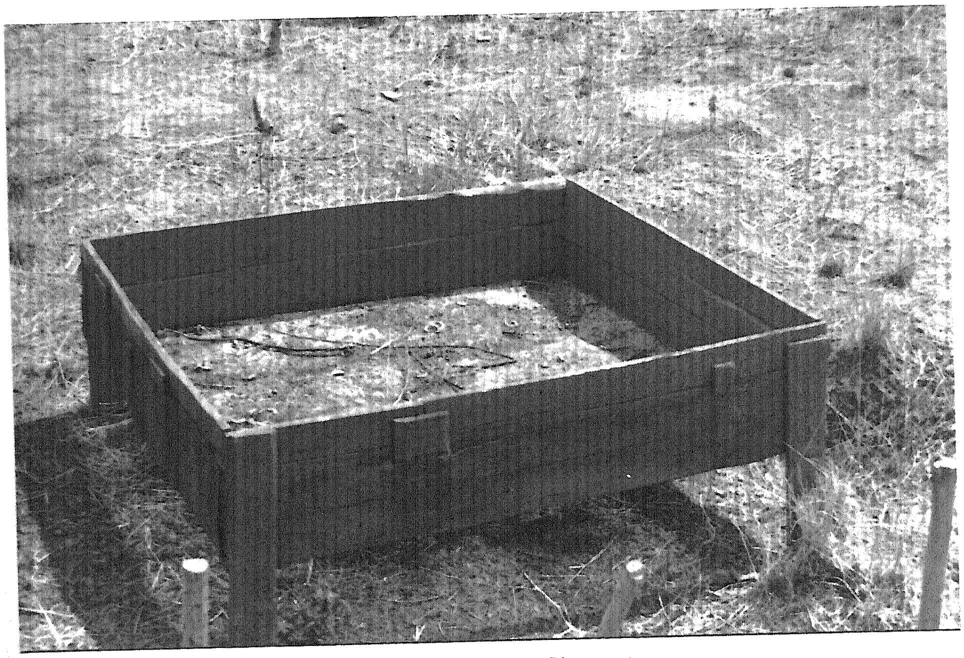
The trend of seasonality in litter production of *Acacia tortilis* at different microsites during 1997 and 1998 are depicted in Figs12 and 13, respectively. It is evident from the figures that most of the litter fall (around 93 %) was concentrated during January to June when compared to July to December at all the microsites during both the years. Peak litter production was recorded during May closely followed by April at all the microsites. Total litter production during 1997 varied from 3.21 to 5.40 t/ha with the increase in tree density. In 1998, generally, lower level of litter production was recorded. This could be attributed to heavy lopping of trees during 1998.

Leaves contributed about 72 per cent of the total litter fall receipt during both the years. It was followed by branch litter (23 %) and miscellaneous litter production (4 %). Leaf litter was recorded during all the months whereas branch and miscellaneous litter production were limited to some months only. Generally branch litter was produced during March to June and miscellaneous litter was produced during April and May. Peak leaf, branch and miscellaneous litter fall were generally recorded during May (Figs 12 and 13).

Plate 5



Litter trap (1mx1m) for litter fall studies at the experimental site



A close-up view showing fallen litter in litter trap

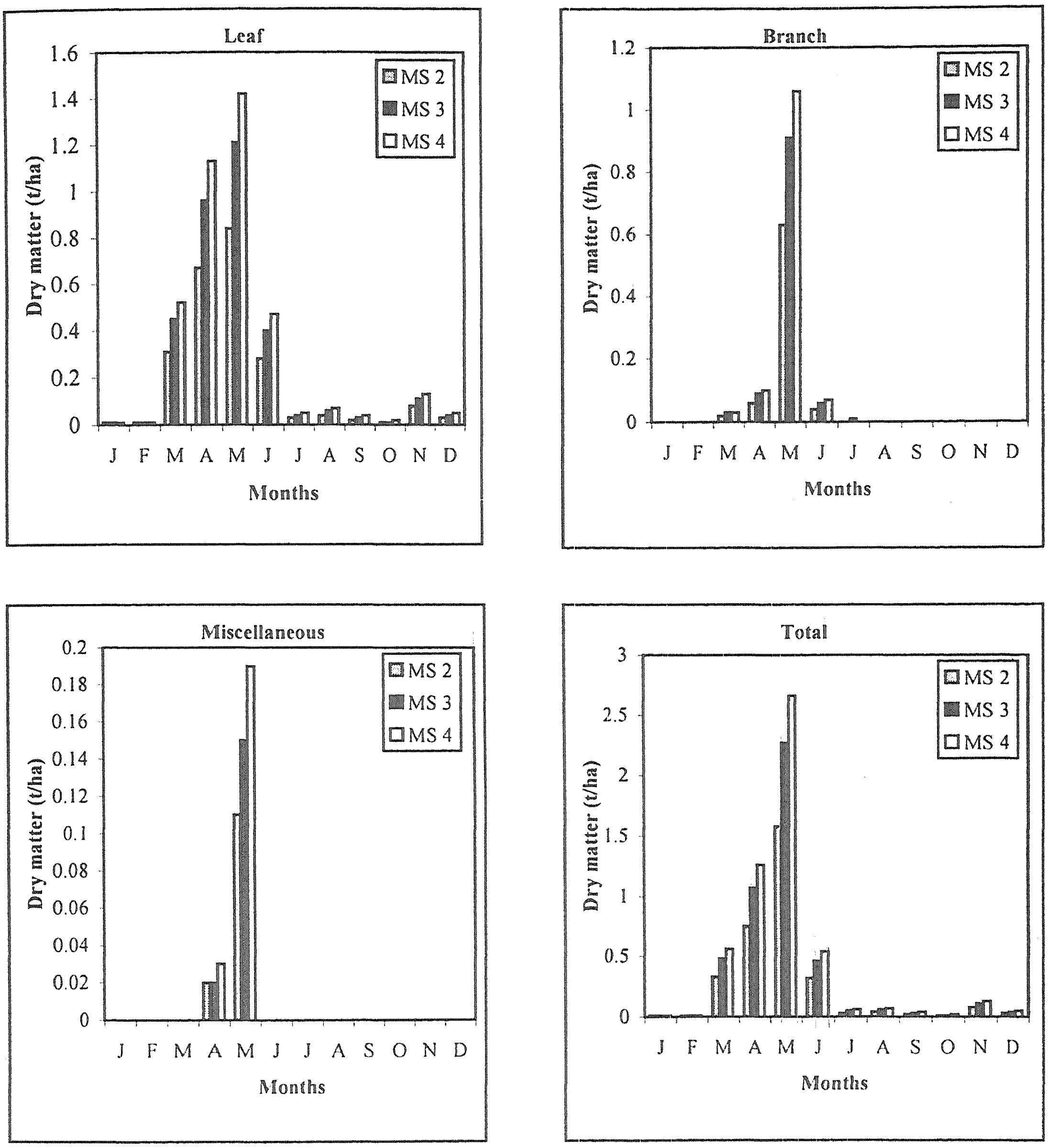


Fig. 12
Trend of seasonality in tree litter (*Acacia tortilis*) production at different microsites during 1997.

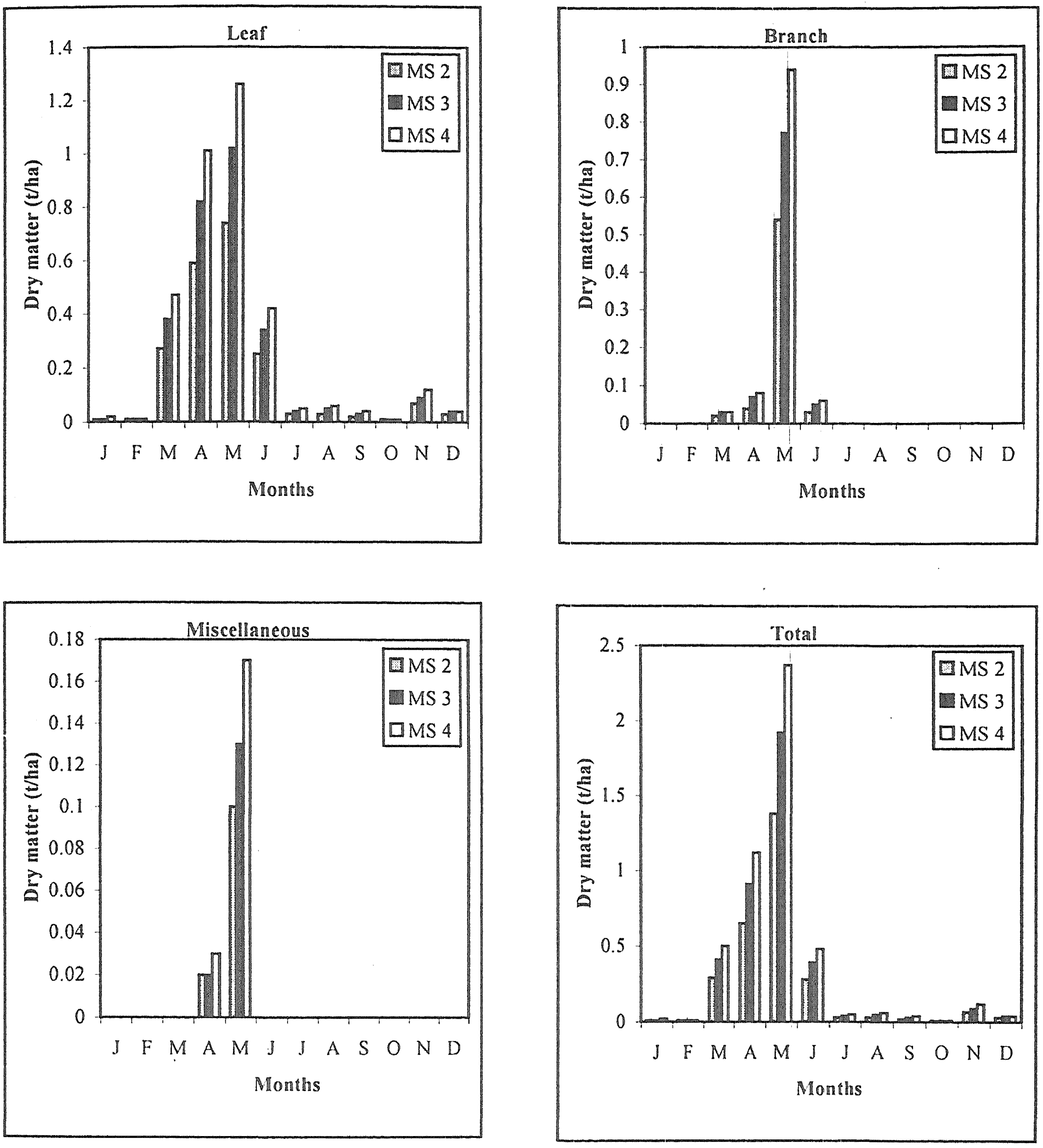


Fig. 13
Trend of seasonality in tree litter (*Acacia tortilis*) production at different mocrosites during 1998.

Litter production based on two years data at the three microsites of the study is presented in Table 23. At this growth stage total litter productivity varied from 3.00 to 5.05 t/ha/yr with the increase in tree density. During 1997 and 1998 significant difference in leaf litter production was observed between all the three microsites. The litter production on account of branch and miscellaneous tree parts at different microsites showed an increasing trend with the increase in tree density. However, the differences were not significant. As in leaf litter production, during 1997 and 1998 significant difference was found in total litter production between microsite 2 and microsite 4 only. Thus it shows that especially the leaf litter play a major role in structure and functioning of a terrestrial ecosystem.

The pattern of litter fall and subsequent nutrient release has been more extensively studied for temperate areas when compared to tropical areas (Bray and Gorham, 1964). However, in India, several studies on annual litter production are available from deciduous forests and old plantation (Puri, 1953; Bhatnagar, 1968; Singh, 1968; Gour and Pandey, 1978; Subba Rao *et al.*, 1972; George, 1982; Naik and Srivastava, 1985; Prasad and Mishra, 1985; Rajvanshi and Gupta, 1985; Girolkar and Naik, 1987; Chaubey *et al.*, 1988; Pandey and Sharma, 1988; Paulsamy *et al.*, 1990; Joshi, 1993; Singh and Gupta, 1993; Hosur *et al.*, 1997; Mishra and Nisanka, 1997; Jammaludden and Mohan Kumar, 1999). The leaf litter production varied from 1.08 to 17.3 t/ha in deciduous forests of India depending upon site quality, latitude, tree species and their density. Recently litter production under multipurpose tree species in agroforestry situation has been studied by some workers (Mallik and Prakash, 1993; Singh and Keshwa, 1993). Under 6 year old plantation (500 tree/ha) of *Bombax ceiba, Albizia lebbek, Terminalia arjuna, Dalbergia sissoo* and *Melia azadirach*; the annual litter fall varied from 0.7 to 1.0 t/ha (Mallik and Prakash, 1993).

Bray and Gorham (1964) have shown an inverse relationship between annual leaf litter production and latitude of the locality. As per their calculation

Table 23
Annual litter production (t/ha) from *Acacia tortilis* in silvopastoral systems (1997, 1998).

Density	Leaf	Branch	Misc.	Total
		Year 1		
MS 2	1.9	0.5	0.8	3.2
MS 3	2.9	0.7	1.0	4.6
MS 4	3.4	0.8	1.2	5.4
CD (<0.05)	1.1	0.4	0.3	1.9
		Year 2		
MS 2	1.7	0.4	0.7	2.8
MS 3	2.4	0.6	0.9	3.9
MS 4	3.0	0.7	1.1	4.8
CD (<0.05)	1.3	NS	NS	1.7
		Mean of Two Years		
MS 2	1.80	0.45	0.75	3.00
MS 3	2.65	0.65	0.90	4.20
MS 4	3.20	0.75	1.10	5.05

the potential annual leaf litter production on this site could be 6.32 t/ha. Thus peak annual litter production at microsite 4 (5.77 t/ha) is still less by about 9 per cent of the potential. This could be attributed to poor site quality.

Nutrient Concentration

The range of variation in nutrients *viz.*, nitrogen, phosphorus, potassium, calcium in various plant parts of standing vegetation in silvopasture based on *Acacia tortilis* across the microsites are shown in Tables 24 and 25. The tree parts maintained higher range of nitrogen concentration when compared to pasture components. In trees, highest average concentration of nitrogen was recorded in pods (2.65 %) followed by leaf (2.19 %), branch (0.87 %), root (0.61 %) and bole (0.21 %). The aboveground pasture component had higher nitrogen concentration (0.66 %) when compared to the belowground component (0.47 %). Like nitrogen, higher range of phosphorus concentration was recorded in tree parts when compared to pasture components. In trees, highest average phosphorus concentration was recorded in pod (0.18 %) followed by leaf (0.12 %), root (0.09 %), branch (0.05 %) and bole (0.04 %). The aboveground pasture components had higher phosphorus concentration (0.02 %) when compared to the belowground components (0.01 %) (Table 24).

Pods and leaves of the tree generally maintained higher range of potassium concentration when compared to pasture components. In trees, highest average concentration of potassium was recorded in leaf (0.48 %) followed by pod (0.47 %), root (0.27 %), branch (0.26 %) and bole (0.09 %). The aboveground pasture components had higher potassium concentration (0.66 %) when compared to belowground components (0.41 %). Like potassium, the leaf and pod maintained higher range of calcium concentration when compared to pasture components. Highest average concentration of calcium was recorded in leaf (1.78 %) followed by pod (1.42 %), branch (0.42 %), root (0.39 %) and bole (0.23 %). The aboveground pasture components maintained marginally higher

Table 24
Mean nutrient concentration (%) in different plant parts of *Acacia tortilis* based silvopastoral system at the study site (N and P).

System	Component	Nitrogen Range	Av.	Phosphorus Range	Av.
Pasture					
	AG	0.49-0.78	0.66	0.01-0.03	0.02
	BG	0.31-0.60	0.47	0.01-0.02	0.01
Tree					
	Leaf	1.97-2.65	2.19	0.11-0.13	0.12
	Pod	2.30-3.13	2.65	0.18-0.19	0.18
	Bole	0.13-0.36	0.21	0.02-0.05	0.04
	Branch	0.74-0.91	0.87	0.03-0.06	0.05
	Root	0.38-0.74	0.61	0.08-0.10	0.09

Table 25
Mean nutrient concentration (%) in different plant parts of *Acacia tortilis* based silvopastoral system at the study site (K and Ca).

System	Component	Potassium Range	Av.	Calcium Range	Av.
Pasture					
	AG	0.33-0.61	0.66	0.63-0.97	0.89
	BG	0.32-0.54	0.41	0.53-0.89	0.83
Tree					
	Leaf	0.39-0.57	0.48	1.57-1.98	1.78
	Pod	0.37-0.54	0.47	1.36-1.58	1.42
	Bole	0.08-0.10	0.09	0.19-0.27	0.23
	Branch	0.23-0.29	0.26	0.38-0.49	0.42
	Root	0.21-0.33	0.27	0.34-0.43	0.39

calcium concentration (0.89 %) when compared to the belowground components (0.83 %) (Table 25).

The concentration of all the nutrients *viz.*, N, P, K and Ca in leaf litter was lower when compared to standing leaf. Excepting P and Ca in branch and leaf and Ca in miscellaneous, lower concentration of all the nutrients was recorded when compared to corresponding live standing vegetation. In leaf litter, highest reduction was recorded in case of nitrogen (32.4 %) followed by potassium (29.1 %). In branch litter, highest reduction was in case of potassium (38.4 %) followed by nitrogen (6.8 %). In miscellaneous litter, highest reduction was in case of nitrogen (32.4 %) followed by potassium (29.7 %).

The range of variation in nutrients *viz.*, nitrogen, phosphorus, potassium and calcium in various litter parts of *Acacia tortilis*, across the microsites, is shown Table 26. The leaf litter contained higher concentration of potassium and calcium, and miscellaneous litter contained higher concentration of nitrogen and phosphorus. Similar trend of nutrient concentration has been reported by Hosur *et al.* (1997) in six different tree species *viz.*, *Tectona grandis*, *Dalbergia sissoo*, *Acacia catechu*, *Dendrocalamus strictus*, *Eucalyptus tereticornis* and *Casuarina equisetifolia*.

Table 26
Mean nutrient concentration (%) in different litter parts of *Acacia tortilis* at the study site.

	Litter part		
Nutrients	Leaf	Branch	Misc.
N	1.48±0.76	0.81±0.21	1.79±0.32
P	0.12±0.01	0.08±0.01	0.18±0.03
K	0.34±0.08	0.16±0.03	0.33±0.06
Ca	1.78±0.13	0.75±0.11	1.57±0.09

Nutrient accumulation in individual plant tissues of standing vegetation is usually a reflection of soil fertility status. The photosynthetic capacity of foliage is usually correlated with nutrients, especially of nitrogen (Natar, 1972; Field and Mooney, 1986).

In tropics, nutrient concentration is usually higher in leaf/pod, it appears that in these situation relatively more of the photosynthetate produced by trees are allocated to leave (Whittaker and Likens, 1975). Similar observation has been reported by Sharma *et al.* (1988) in old *Dalbergia sissoo* plantation in India. They found that almost all nutrients, excepting calcium were higher in the foliage when compared to other tree components. Montagnini *et al.*, (1991) and Montagnini and Sancho (1994) reported similar trend in young plantation of several multipurpose tree species *viz.*, *Vochysia hondurensis*, *V. ferruginea*, *Styphnodendron excelsum* and *Hyeronima alchorneoides* in humid lowlands of Costa Rica. However, in this study, pods maintained a higher level of nitrogen, phosphorus and potassium concentration when compared to leaf. However, leaf maintained higher calcium concentration when compared to pod. The production of pods in this species is quite low when compared leaf. In such a situation the leaves have the most important role to play in nutrient turnover. Generally lower level of nutrient concentration is reported in litter parts when compared to their aboveground counter parts (Raghuvanshi *et al.*, 1990; Hosur *et al.*, 1997; Jamaludheen and Mohan Kumar, 1999). The present study also confirms this finding.

Nutrient Accumulation in Standing Biomass

Trend of nutrient accumulation by the ground vegetation in aboveground and belowground parts is depicted in Table 27. The accumulation of all the nutrients was higher in aboveground parts. The accumulation of nutrients decreased from microsite 2 to microsite 4, primarily on account of less pasture yield with increase in tree density.

Table 27
Nutrient accumulation (kg/ha/year) by the ground vegetation in different silvopastoral systems (1997, 1998).

Microsite	Nitrogen		Phosphorus		Potassium		Calcium	
	AG	BG	AG	BG	AG	BG	AG	BG
MS 2	21.3	4.6	0.6	0.09	15.2	4.0	28.8	8.2
MS 3	20.1	3.7	0.6	0.07	14.3	3.2	27.2	6.5
MS 4	17.4	3.2	0.5	0.06	12.4	2.8	23.4	5.7

Trend of nutrient accumulation in different parts of *Acacia tortilis* (> 13 years) at various microsites is depicted in Table 28. The accumulation of nutrients increased from microsite 2 to microsite 4, primarily on account of more total tree biomass with increase in tree density. Highest accumulation of nitrogen was in branch followed by root, pod, bole and leaf. However, highest accumulation of phosphorus, potassium and calcium was also in branch followed by root, bole, pod and leaf.

Highest accumulation of nutrients was registered in case of nitrogen (536 – 699 kg/ha) followed by calcium (292 – 380 kg/ha), potassium (168 – 219 kg/ha) and phosphorus (42 – 53 kg/ha). Most of these nutrients was locked up in aerial parts. The proportion of nutrient lockup in aerial parts varied from 86 to 88 per cent, 74 to 77 per cent, 81 to 83 per cent and 84 to 86 per cent in case of nitrogen, phosphorus, potassium and calcium, respectively. Similar trends of nutrient accumulation has been reported from 24 year old *Dalbergia sissoo* plantation (Tewari, 1994). Raizada and Padmaiah (1993) reported huge accumulation of nutrients in plantation of *Leucaena leucocephala*, *Acacia nilotica*, *Eucalyptus* hybrid and *Azadirachta indica*.

Thus heavy thinning in natural forests or plantations results in removal of soil nutrient pools besides many other effects *viz*., chemical and physical soil

Table 28
Nutrient accumulation (kg/ha) in *Acacia tortilis* (> 13 years) at the study site (1997-1998).

Microsite	Bole	Branch	Leaf	Pod	Root
			Nitrogen		
MS 2	28.0	380.5	5.9	49.0	72.8
MS 3	29.0	464.6	8.5	48.0	81.9
MS 4	37.6	512.7	10.9	52.7	85.0
			Phosphorus		
MS 2	5.3	21.9	0.3	3.3	10.7
MS 3	5.5	26.7	0.4	3.2	12.0
MS 4	7.1	29.5	0.6	3.6	12.5
			Potassium		
MS 2	12.0	113.7	1.3	8.7	32.2
MS 3	12.4	138.8	1.9	8.5	36.2
MS 4	16.1	153.2	2.4	9.3	37.6
			Calcium		
MS 2	30.7	183.7	4.8	26.2	46.6
MS 3	31.8	224.2	6.9	25.7	52.3
MS 4	41.1	247.5	8.9	28.2	54.3

factors, nutrient supply, root dynamics, decomposition rate, soil biota (Bath, 1980; Seasted and Crossley, 1981; Vitousek and Matson, 1985). There are several reports of about depletion of soil nutrients of as a result of large scale tree harvesting. For instance, Nwoboshi (1980) reported 10-25 per cent reduction in soil N pools as a result of heavy thinning in teak plantations in Nigeria. Similarly, Raghuvanshi *et al.* (1990) reported the loss of soil organic carbon and total N by 13 and 20 per cent, respectively as a result of the harvesting of bamboo.

The importance of micro nutrient accumulation in vegetation component has been discussed by Andriesse and Schelhaas (1977). They concluded that in all the systems, the maintainence of tree vegetation during cropping period is probably crucial for preventing critical initial loss of nutrients. The results obtained in this study confirm this.

Recyclable Nutrients

The potential recyclable nutrients through litter of *Acacia tortilis* are presented in Table 29. Return of nitrogen through litter fall ranges from 43.6 to 73.1 kg/ha with the increase in tree density. Similar returns in case of phosphorus, potassium and calcium were in the range of 3.9 to 6.4 kg/ha, 9.3 to 15.8 kg/ha and 47.2 to 79.8 kg/ha, respectively. Major proportion of nutrient return was through leaf. It accounted for 61 to 65 per cent in case of nitrogen, 56 to 60 per cent in case of phosphorus, 66 to 70 per cent in case of potassium and 68 to 71 per cent in case of calcium. Next in order was miscellaneous litter that contributed 27 to 31 per cent in case of nitrogen, 31 to 33 per cent in case of phosphorus, 23 to 27 per cent in case of potassium and 21 to 25 per cent in case of calcium.

Similar results have also been reported for different plantation and forests in Uttar Pradesh (George, 1986) and Karnataka (Sugur, 1989; Hosur *et al.*, 1997).

These results indicate that ground floor under silvopastures is an important place for accumulation and recycling of nutrients. The nutrients in litter were equivalent to 7 to 15 per cent of nutrients contained in aboveground biomass,

Table 29
Potential recyclable nutrients (kg/ha) through litter of *Acacia tortilis* (> 13 years) at the study site (1997-1998).

Microsite	Leaf	Litter Branch	Misc.	Total
		Nitrogen		
MS 2	26.6	3.6	13.4	43.6
MS 3	39.2	5.2	16.1	60.5
MS 4	47.3	6.1	19.7	73.1
		Phosphorus		
MS 2	2.2	0.4	1.3	3.9
MS 3	3.2	0.5	1.6	5.3
MS 4	3.8	0.6	2.0	6.4
		Potassium		
MS 2	6.1	0.7	2.5	9.3
MS 3	9.0	1.0	3.0	13.0
MS 4	11.0	1.2	3.6	15.8
		Calcium		
MS 2	32.0	3.4	11.8	47.2
MS 3	47.1	4.9	14.1	66.1
MS 4	57.0	5.5	17.2	79.8

depending on specific nutrients and microsites. These values are on a lower side compared to the value reported by Wang *et al.* (1991) in tropical situations. They found that with the exception of potassium, nutrients in forest floor litter were equivalent to a large proportion (16-50 %) of nutrients contained in the aboveground biomass. They concluded that if tiller were left in floor after harvest, it would represent a substaintial reservoir of nutrients for next rotation. Montagnini and Sancho (1994) obtained similar results under plantation of *Styphnodendron excelsum*, *Vochysia hondurensis*, *V. ferruginea* and *Hyeronima alchorneoides* at the Atlantic lowlands of Costa Rica. They found that forest floor was particularly important for recycling of nitrogen, calcium, magnesium and phosphorus at that site.

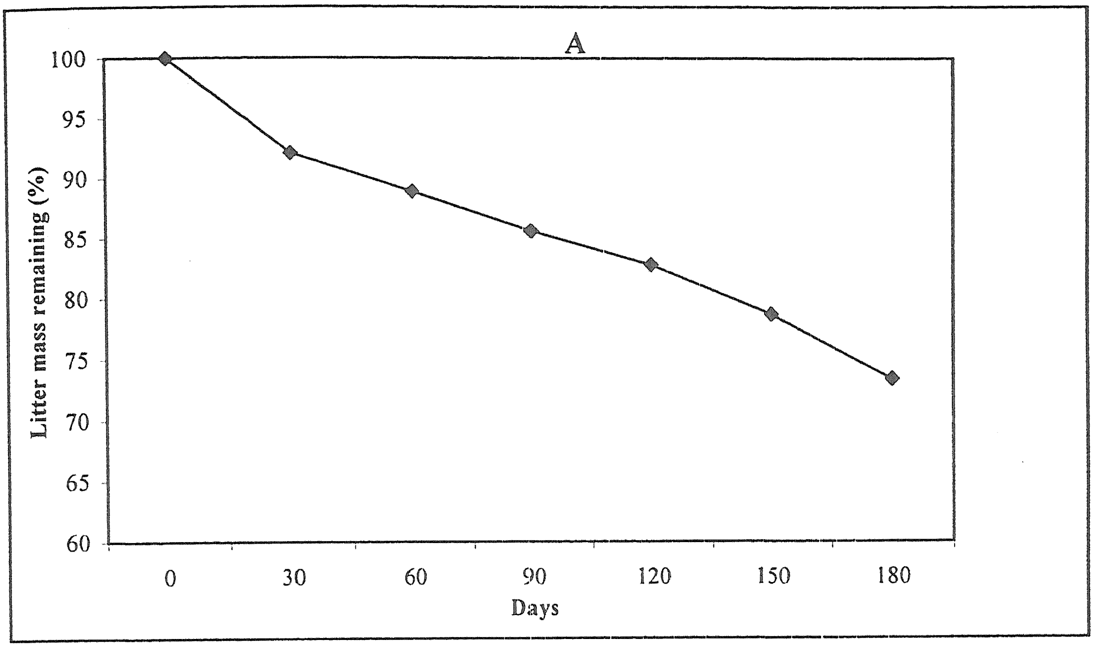
Silvopastures have potential to ameliorate productivity of degraded lands on account of several gains as on result of tree plantation. The most significant among these is the production of litter and nutrient recycling through it. This helps in build up of organic matter and important nutrients elements in the soil (Princely and Swift, 1986). It is also reported to protect soil from erosion impact of rains and hence reduces surface water runoff (Bell, 1973).

Leaf Litter Decomposition

Leaf litter is the most important component of litter for organic matter, energy and nutrient release in forest ecosystems. The litter reaching forest floor decay and gradually become incorporated into the upper horizon of mineral soil through activity of soil organisms (Macfadyen, 1963).

Laboratory Condition

Trends of loss in litter mass and nutrient release, in leaf litter of *Acacia tortilis* after decomposition in controlled laboratory condition for 180 day are depicted in Fig. 14. In a period of 180 days only 73.4 per cent of leaf litter biomass remained in the bags. As a result of mass loss the concentration of all the



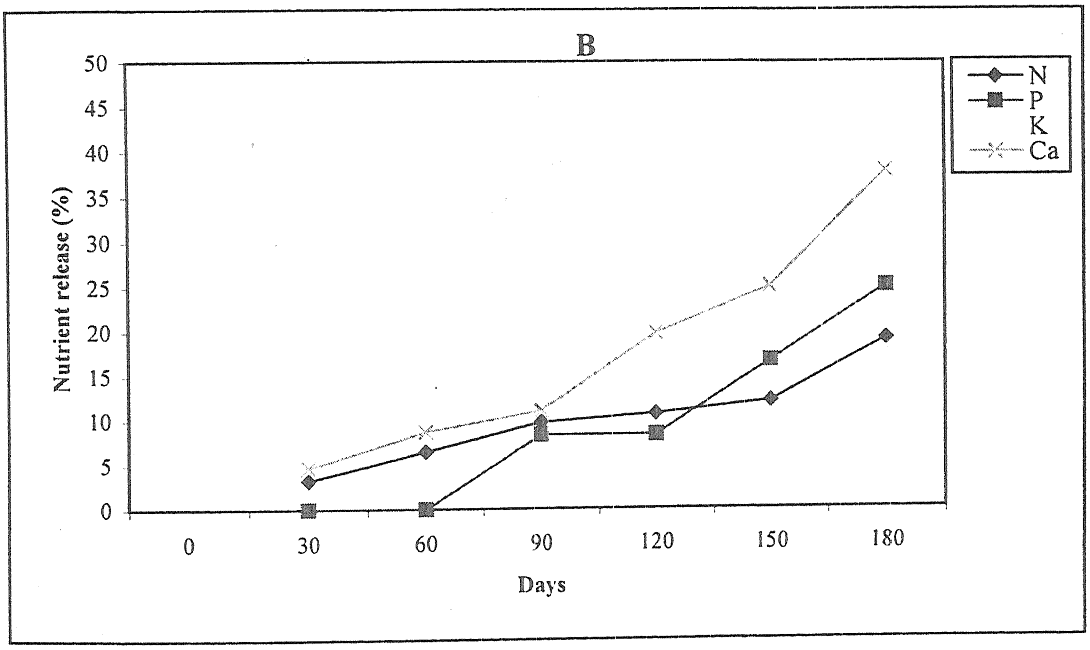


Fig. 14

A. Trend of litter mass remaining in tree leaf litter of *Acacia tortilis* after decomposition in laboratory condition.

B. Trend of nutrient release (%) by decomposing tree leaf litter of *Acacia tortilis* in laboratory condition.

nutrients decreased with time. Maximum reduction at 180 days was recorded in case of potassium (45.9 %) followed by calcium (37.8 %), phosphorus (25.0 %) and nitrogen (19.1 %).

Field Condition

The trend of loss in litter mass (at different microsites) and nutrient release, in leaf litter of *Acacia tortilis* after decomposition in field condition for 24 months are depicted in Fig. 15. In a period of 24 months 26.9 to 31.6 per cent of leaf litter remained in the bags. A trend of increased rate of decomposition was observed with the increase in tree density. As a result of mass loss the concentration of all the nutrients decreased with time. Maximum reduction at 24 months was recorded in case of potassium (73 %) followed by calcium (65 %), nitrogen (60 %) and phosphorus (58 %).

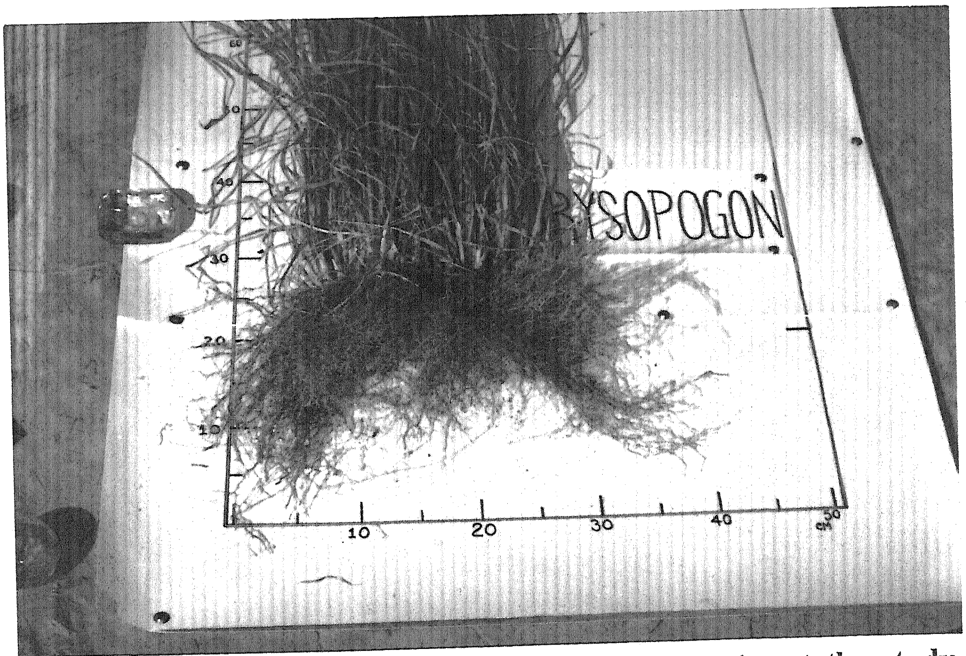
Generally, rapid rate of leaf litter decomposition was observed during rainy season. This is comparable with reports in tropical forests (Madge, 1965), tropical rain forests (Cormforth, 1970), tropical dry deciduous forests (Rajvanshi and Gupta, 1980), montane oak forest of Garhwal Himalayas (Pant and Tewari, 1992), agroforestry plantation in lowlands of Costa Rica (Montagnini *et al.*, 1993).

The high rate of decomposition in rainy season could be attributed to suitable temperature and moisture condition for the activity of decomposers (microorganism) and frequent rain source for reaching of water soluble substances (Alexander, 1977). The higher decomposition rate at microsite 4 followed by microsite 3 and 2 in that order may be attributed to more favorable microclimatic condition for the activity of decomposers under dense plantation.

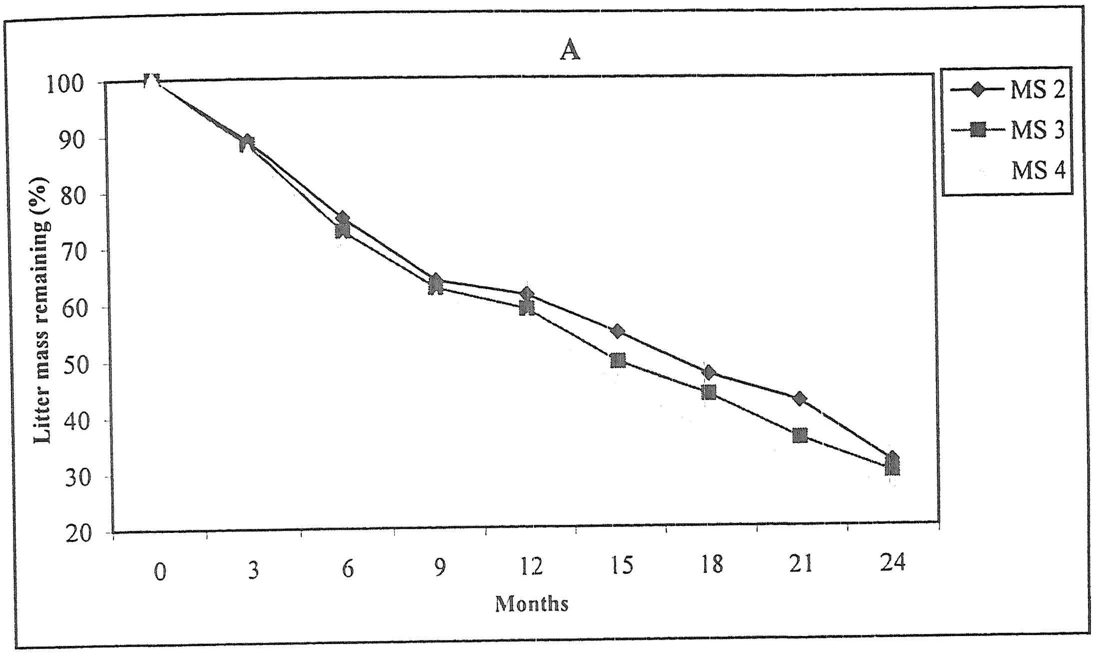
The residual moisture of rainy season and moderate temperature in early months of winter may be responsible for higher decomposition rate in winter when compared to spring. Relatively lower rate of decomposition during spring

Plate 6

Placement of litter bags at the experimental site for estimating loss in litter mass



Growth of *Chrysopogon fulvus* a major grass species at the study site (Also showing the root system)



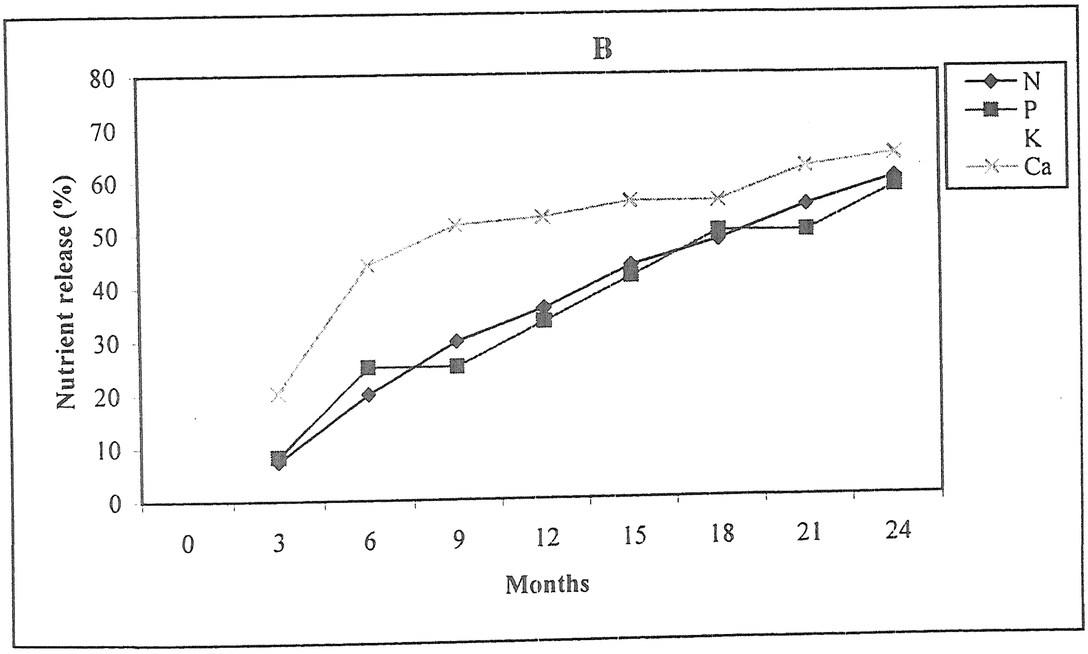


Fig. 15

A. Trend of litter mass remaining in tree leaf litter of *Acacia tortilis* after decomposition in field condition.

B. Trend of nutrient release (%) by decomposing tree leaf litter of *Acacia tortilis* in field condition.

and summer season may be due to paucity of soil water resulting from low rainfall and large insolation period.

The trend of litter decomposition of *Acacia tortilis* at the present site is quite comparable to similar studies on forest tree litter decomposition in tropical (Paulsamy *et al.*, 1992), temperate (Saxena *et al.*, 1978; Pant and Tewari, 1992) and agroforestry (Malik and Prakash, 1993) situations.

Release of nutrients from decaying organic matter in soil is a critical step in ecosystem function. If the nutrients are released too fast, they can be through soil leaching or volatization. In contrast, if decomposition is too slow, insufficient nutrient are made available with the result that plant growth can be inhibited (Jordan, 1985). The pattern of maximum weight loss and nutrient release during growing season at this site has important implication in uptake of nutrients. Microsite 4 appear to be the most efficient in releasing nutrient through tree leaf litter when compared to other microsite.

Nutrient Budget

Nutrient budget for nitrogen, phosphorus, potassium and calcium were prepared for three silvopasture microsites of study (Fig. 16). The dotted lines indicate the possible path of recyclable nutrients as a result of root decomposition/decay and litter decomposition.

It is evident from the figure that nutrient lockup in below and aboveground components increased with tree density. This could be attributed to more uptake of nutrients as a result of more extensive root system. The per cent nutrient lockup in above + belowground (of total soil pool) varied from 2.50 to 3.20 per cent in case of nitrogen, 6.30 to 7.90 per cent in case of phosphorus, 0.27 to 0.34 per cent in case of potassium and 0.34 to 0.43 per cent in case of calcium. The per cent nutrient lockup increased with the tree density. The per cent of potential recyclable nutrients through leaf litter (of aboveground nutrients) varied from 9.1 to 11.6 per cent in case nitrogen, 12.9 to 14.6 per cent in case of phosphorus, 6.0

AG (Nutrients in kg/ha)

Nutrients	Microsites		
	MS2	MS3	MS4
N	484	570	631
P	31	36	41
K	151	176	193
Ca	274	316	349

Litter (Nutrients in kg/ha)

Nutrients	Microsites		
	MS2	MS3	MS4
N	44	60	73
P	4	5	6
K	9	13	16
Ca	47	66	80

BG (Nutrients in kg/ha)

Nutrients	Microsites		
	MS2	MS3	MS4
N	77	85	88
P	11	12	12
K	36	39	40
Ca	55	59	60

Soil Pool
(Nutrients in kg/ha)

C	1.16×10^5
N	2.24×10^4
P	6.72×10^2
K	6.72×10^4
Ca	9.40×10^4

Fig. 16
Nutrient budgets in respect of nitrogen, phosphorus, potassium, and calcium at the three silvopasture sites of study (1997-1998).

to 8.3 per cent in case of potassium and 17.2 to 22.9 per cent in case of calcium. Additional quantity of recyclable nutrients may also reach the ground floor through twig/branch/miscellaneous litter. This, however, was not estimated in the present study owing to their lower relative proportion of the total detritus fall or elemental concentration.

Nitrogen cycling through various components is believed to be an important strategy for ecosystem analysis (Pomeroy, 1970). The pattern of nitrogen storage and release observed at this site is in confirmity with the results reported by Cole *et al.* (1968) for Douglas Fir ecosystem, Borman *et al.* (1977) for Northern Hardwood ecosystem, Misra (1979) for natural grassland and Pandeya and Sidha (1989) for arid and semiarid grazing lands.

The phosphorus level in soil are controlled by atmospheric variables on one hand through growth of plant shoots (uptake) and on other hand by mineralization of litter and dead roots by microbial activity. The pattern of phosphorus storage and release at this site is supported by the work of Cole *et al.* (1968) for Douglas Fir ecosystem, Cole *et al.* (1977) for semiarid grassland ecosystem, Dadhich (1979) in some forest trees and Bawa (1992) for Himalayan rangelands.

Increased root activity generally induces more potassium uptake and maximum rate of return of potassium to soil has been recorded through root decomposition (Pandeya and Sidha, 1989). Along with decomposition process it is also contributed by diffusion rate through cell wall in roots (White, 1971; 1973). There are some reports pertaining to potassium cycle on sandy plane of Rajasthan (Singh and Joshi, 1986) and temperate grassland (Kapoor and Singh, 1992). These systems retained very little potassium in aboveground components and released substantially through root and litter decomposition. Similar trend has been observed in this study also. It signifies that such systems may remain stable for some more time in apparent absence of exchangeable potassium.

Low level of calcium lockup in standing vegetation and quite high amount in soil pool indicates lower level of demand of this nutrient by silvopastures. The pattern of calcium storage and release at this site is supported by the work of Bawa (1992) while studying nutrient budgets of Himalayan grassland ecosystem.

Soil Fertility

Many workers have reported increased availability of nutrients under tree cover (Sanchez *et al.*, 1985; Sanchez, 1987; Nair, 1989). Also symbiotic nitrogen fixation by trees often results in increased soil nitrogen availability (Alpizar *et al.*, 1986; Montagnini *et al.*, 1986; Dommergues, 1987). In view of this an attempt was made to evaluate the accumulative changes in soil fertility under trees across the microsites during study period. Table 30 present data related to changes in soil fertility status.

It is evident from the table that there was almost no change in total nitrogen, total phosphorus, available phosphorus and available calcium content during this period. Maximum increase was registered in case of available nitrogen (9.3 %) followed by total potassium (9.1 %), organic carbon (8.8 %), organic matter (4.1 %) and total calcium (2.3 %). Generally higher level of nutrients under trees during two years may be due to litter addition and their decay. Root decay may be another mechanism in this respect (Young, 1991; George and Mohan Kumar, 1998). Soil fertility enhancement through litter fall, litter and root decomposition and nutrient cycling in agroecosystems involve complex and long term processes that can not be quantified by two year data as presented here. These results do, however, provide a basis for comparing litter fall and decomposition processes in silvopastoral systems involving different multipurpose tree species.

Lundgren (1978, 1979) proposed that ameliorating effect of plantation forests on soil occur only during the 5 to 10 year period immediately following canopy closure (the "fallow enrichment phase"). In fact, during maximum

Table 30
Changes in soil fertility status under *Acacia tortilis* based silvopastures (> 13 years) after two years (1997- 1998).

Soil fertility	Range	Average
	Initial	
Organic matter (%)	0.8200 - 1.07	0.93
Organic carbon (%)	0.4700 - 0.63	0.52
Total nitrogen (%)	0.0880 - 0.123	0.10
Available nitrogen (%)	0.0370 - 0.043	0.039
Total phosphorus (%)	0.0030 - 0.007	0.003
Available phosphorus (%)	0.0003 - 0.0008	0.0006
Total potassium (%)	0.1800 - 0.47	0.30
Total calcium (%)	0.2300 - 0.62	0.42
Available calcium (%)	0.1650 - 0.221	0.20
	After 2Years	
Organic matter (%)	0.82 - 1.18	0.97
Organic carbon (%)	0.48 - 0.69	0.57
Total nitrogen (%)	0.088 - 0.125	0.10
Available nitrogen (%)	0.039 - 0.047	0.043
Total phosphorus (%)	0.003 - 0.007	0.003
Available phosphorus (%)	0.0003 - 0.0008	0.0006
Total potassium (%)	0.21 - 0.51	0.33
Total calcium (%)	0.23 - 0.64	0.43
Available calcium (%)	0.168 - 0.224	0.20

production phase actual deterioration in site quality can occur - mineral nutrients are absorbed by trees while litter accumulates on forest floor, but condition are unfavourable for decomposition of organic matter.

In this study where *Acacia tortilis* trees approached the canopy closure stage, the soil enrichment in almost all the nutrients indicate potential role of this species in ameliorating soil fertility in medium to long term. However, as with all species, rates of nutrient uptake by trees and their recycling through litter varied for each nutrient.

CHAPTER 5

CONCLUSION

CONCLUSION

The studies on productivity of *Acacia tortilis* (Forsk.) Hayne based silvopastoral systems in Bundelkhand region have shown interesting results.

At a microscale, the grown up trees (> 13 years) modified the microclimate under it to a great extent. Lesser availability of solar radiation/ photosynthetically active radiation to the ground vegetation was mainly due to tree density and canopy structure of the systems. Temperature (air and soil) was found to be affected by the availability of solar radiation. Higher temperature regime was recorded in open situation.

Higher relative humidity under silvopastures was attributed because of lower radiation availability and a more favourable soil moisture regime. Canopy transpiration could also be one of the reasons.

Generally, silvopastures maintained higher soil moisture regime at different depths. Also the soil moisture content generally increased with the increase in tree density. Besides type and density of vegetation cover, type of clay/organic matter at a particular microsite appeared to have influence in determining soil moisture regime.

The total density of ground vegetation was higher in open situation when compared to canopy situation. The share of perennial and annual grasses decreased markedly under dense canopy situation. However, share of legumes and weeds increased under canopy. Vigour attributes *viz.*, plant height, tussock diameter, number of tiller/tussock showed a decreasing trend with increase in canopy density in respect of the five perennial grasses *viz.*, *Chrysopogon fulvus*, *Cenchrus ciliaris*, *Heteropogon contortus*, *Sehima nervosum*, *Dicanthium annulatum* at the study site.

Studies on phenology of *Acacia tortilis* revealed that the tree species has several xerophytic adaptations to protect itself from rigours of dry season. Also, the leaf replacement strategy during summer months appeared to minimize stress

by leaf fall and maximize photosynthetic activity during wet warm season of the year through flushing. Trees attained a plateau in height growth at 14^{th} year. The canopy spread and diameter growth decreased consistently with the increase in tree density.

As expected, highest reduction in aboveground pasture production was found in dense canopy situation followed by medium and light canopy. Similar trend was found in case of belowground biomass. Standing tree biomass increased with the increase in tree density. Similarly, the biomass obtained as a result of lopping also increased with the increase in tree density. The total aboveground productivity and total biomass productivity (aboveground + belowground) under silvopastures increased from 2.17 to 2.53 times and 2.02 to 2.27 times when compared to only pasture land use system. The top feed maintained much higher level of crude protein when compared to the pasture component.

The litter fall in *Acacia tortilis* was mostly concentrated during January to June, with peaks during May and April. Among litter, the leaves contributed about 72 per cent of total litter fall receipt. The litter production increased with increase in tree density.

The accumulation of all the nutrients *viz.*, nitrogen, phosphorus, potassium and calcium was higher in aboveground parts. Among nutrients, highest accumulation was registered in case of nitrogen followed by calcium, potassium and phosphorus. Thus, heavy thinning of trees at one time may result in removal of soil nutrient pools besides many other deterimental effects on soil.

The ground floor under silvopastures was an important place for accumulation and recycling of nutrients. Return of nutrients through litter fall increased with the increase in tree density. Highest return was registered in case of calcium followed by nitrogen, potassium and phosphorus.

Leaf litter was found to be the most important of various litter parts for nutrient release in silvopastures. Increased rate of leaf litter decomposition was observed with the increase in tree density. As a result of mass loss, the

by leaf fall and maximize photosynthetic activity during wet warm season of the year through flushing. Trees attained a plateau in height growth at 14^{th} year. The canopy spread and diameter growth decreased consistently with the increase in tree density.

As expected, highest reduction in aboveground pasture production was found in dense canopy situation followed by medium and light canopy. Similar trend was found in case of belowground biomass. Standing tree biomass increased with the increase in tree density. Similarly, the biomass obtained as a result of lopping also increased with the increase in tree density. The total aboveground productivity and total biomass productivity (aboveground + belowground) under silvopastures increased from 2.17 to 2.53 times and 2.02 to 2.27 times when compared to only pasture land use system. The top feed maintained much higher level of crude protein when compared to the pasture component.

The litter fall in *Acacia tortilis* was mostly concentrated during January to June, with peaks during May and April. Among litter, the leaves contributed about 72 per cent of total litter fall receipt. The litter production increased with increase in tree density.

The accumulation of all the nutrients *viz*., nitrogen, phosphorus, potassium and calcium was higher in aboveground parts. Among nutrients, highest accumulation was registered in case of nitrogen followed by calcium, potassium and phosphorus. Thus, heavy thinning of trees at one time may result in removal of soil nutrient pools besides many other deterimental effects on soil.

The ground floor under silvopastures was an important place for accumulation and recycling of nutrients. Return of nutrients through litter fall increased with the increase in tree density. Highest return was registered in case of calcium followed by nitrogen, potassium and phosphorus.

Leaf litter was found to be the most important of various litter parts for nutrient release in silvopastures. Increased rate of leaf litter decomposition was observed with the increase in tree density. As a result of mass loss, the

concentration of all the nutrients decreased with time. Maximum decrease was registered in case of calcium closely followed by potassium, nitrogen and phosphorus. The higher rate of decomposition in rainy season was attributed to suitable temperature and moisture condition for the activity of decomposers and frequent rain source for leaching of water soluble substances.

Nutrient budget for nitrogen, phosphorus, potassium and calcium were prepared for three silvopasture microsites. The per cent nutrient lockup in aboveground + belowground (of total soil pool) increased with the tree density. Similarly, per cent of potential recyclable nutrients through leaf litter (of above ground nutrients) increased with the increase in tree density.

An increase in some soil fertility parameters *viz*., available nitrogen, total potassium, organic carbon, organic matter and total calcium was registered during the study period. This may be attributed to litter addition and their decay besides root decay. Soil fertility enhancement through litter fall and their decay, root decomposition and nutrient cycling in silvopastures involve complex and long term processes that cannot be quantified by two year data. However, this provide a base for comparing litter fall and decomposition processes in silvopastoral systems involving different multipurpose tree species.

SUMMARY

SUMMARY

In this study (1997-1998) productivity of *Acacia tortilis* (Forsk.) Hayne based medium rotation silvopastoral systems (13^+ year) maintained at three different densities (about 100, 400 and 600 trees/ha) was compared to open situation in an ecosystem context at the Central Research Farm of the Indian Grassland and Fodder Research Institute, Jhansi. Thus four microsites *viz.*, microsite 1 (open situation), microsite 2 (silvopasture having about 100 trees/ha or light canopy), microsite 3 (silvopasture having about 400 trees/ha or medium canopy), microsite 4 (silvopasture having about 600 trees/ha or dense canopy) were marked for this study.

One of the major control of microclimate in silvopastoral system is solar radiation/photosynthetically active radiation (PAR). In open situation, higher average value of PAR was recorded in 1998 (1987 micro-einstein /m^2/s) when compared to 1997 (1800 micro-einstein/m^2/s). In 1997, highest mean annual PAR availability was recorded in open situation (1671 micro-einstein /m^2/s) followed by light (1060 micro-einstein /m^2/s), medium (963 micro-einstein /m^2/s) and dense (883 micro-einstein /m^2/s) canopies. In 1998, highest mean annual PAR availability was recorded in open situation (1565 micro-einstein /m^2/s) followed by light (1078 micro-einstein /m^2/s), medium (977 micro-einstein /m^2/s) and dense (868 micro-einstein /m^2/s) canopies. The average reduction in PAR availability was found to be 31.1 per cent, 40.3 per cent and 43.6 per cent, respectively under light, medium and dense canopies of *Acacia tortilis*.

At micro scale, temperature (air and soil) was affected by tree canopy. The air temperature was found to be highest in open situation. In 1997, highest mean annual air temperature was recorded in open situation (31.1 °C) followed by light (30.4 °C), medium (30.4 °C), dense (30.2 °C) canopies. In 1998 highest mean annual air temperature was recorded in open situation (30.3 °C) followed by light (30.0 °C), medium (29.6 °C), dense (29.5 °C) canopies. In silvopastoral systems,

a decreasing level of air temperature was observed with the increase in tree density. Soil temperature was found to be highest in open situation. In 1997, highest soil temperature was recorded in open situation (26.4 °C) followed by light (22.6 °C), medium (21.7 °C) and dense (21.5 °C) canopies. In 1998, highest soil temperature was recorded in open situation (25.0 °C) followed by light (22.0 °C), medium (21.0 °C) and dense (19.7 °C) canopies. In silvopastoral systems, a decreasing level of soil temperature was observed with the increase in tree density. The relative humidity (RH) was found to be highest in the dense canopy situation. In 1997, highest relative humidity was found, in dense canopy situation (73 %) followed by medium (70 %), light (68 %) and open situation (68 %). In 1998 highest relative humidity was found in dense canopy situation (70 %) followed by medium (68 %), light (65 %) and open situation (64 %). This could be primarily because of lower radiation levels received under the tree canopies in silvopastoral systems.

The soil moisture is vital to plant growth not only because plants need water for their physiological processes but also because the water contains nutrients in solution. The pattern of soil moisture availability at two depth (depth1, 0-15 cm; depth2, 15-45 cm) at all the four microsites increased with the increase in tree density. Highest mean annual soil moisture was recorded in dense canopy situation (6.95 %) followed by medium (6.81 %), light (6.73 %) and open situation (6.05 %). This may be attributed to the evaporation pattern during the study period. In a particular month generally, higher soil moisture was recorded under trees when compared to open situation.

The higher density of ground vegetation was found in open situation when compared to canopy situation. In dense canopy situation, the share of perennial and annual grasses decreased. However, share of legumes and weeds increased in canopy situation. Vigour attributes *viz*., plant height, tussock diameter, number of tiller/tussock showed a decreasing trend with increase in canopy density in respect of the five perennial grasses *viz*., *Chrysopogon fulvus*, *Cenchrus ciliaris*,

Heteropogon contortus, *Sehima nervosum* and *Dicanthium annulatum* at the study site. Average grass height varied from 53.2 to 62.4 cm. More height was recorded in open situation when compared to canopy situation. In silvopastures, a consistent trend of decrease in height was observed with increase in tree density. Similarly, growth in tussock diameter showed a decreasing trend with increase in canopy density. Such differences between the microsites could be because of the varying microclimate condition prevailing on these sites. The tiller number showed a decreasing showed a decreasing trend with increase in canopy density. Such differences between the microsites are due to canopy density.

The root growth characteristics of five perennial grasses *viz.*, *Chrysopogon fulvus*, *Cenchrus ciliaris*, *Heteropogon contortus*, *Sehima nervosum* and *Dicanthium annulatum* was studied. Maximum depth of root penetration in soil, mean length of root and mean thickness of root was found in *Chrysopogon fulvus* (35.8 cm, 29.6 cm, 0.74 mm). Maximum mean number of root per plant was recorded in *Cenchrus ciliaris* (527/tussock).

The phenology of *Acacia tortilis* showed that the tree species has several xerophytic adaptations to protect itself from rigours of dry season. Flushing and leaf formation occurred in April-May. However, leaf formation continued upto September. The formation of leaf was at its peak during June/July-September. The buds and flowers appeared in April and continued upto May. Pods developed rapidly and reached to full size by June end.

Tree attained a plateau in height growth at 14th year. The average height of trees at different micrositіes decreased from 7.14 to 5.46 m with the increase in tree density. Hence, mean annual increment also decreased from 0.51 to 0.39 m with the increase in tree density. The average spread in canopy decreased from 2.66 m at microsite 2 to 1.84 m at microsite 4. Hence, mean annual increment also decreased from 0.19 to 0.13 m. The average growth in diameter (cd/dbh) decreased from (17.50/15.12 to 12.46/10.36 cm). Hence, mean annual increment in cd/dbh also decreased from 1.25/1.08 cm to 0.89/0.74 cm.

The root growth characteristics of *Acacia tortilis* at the study site show that the length of tap root varied from 0.7 to 1.3 m in different sample trees. The number of major secondary roots varied from 13 to 19. The diameter of tap root varied from 17.6 to 27.4 cm, 7.9 to 10.2 cm and 0.70 to 1.20 cm at the base, center and tip zones, respectively. This indicated that the bulk of roots were confined within 1 m of soil depth.

As expected, highest reduction in aboveground biomass production was recorded in dense canopy situatioin (22.7 %) followed by medium canopy situation (12.4 %) and light canopy situation (8.6 %). Like the aboveground biomass production, significantly higher level of belowground biomass production was recorded in open situation when compared to the canopy situations in both the years. Highest reduction in belowground biomass production was recorded in dense canopy siutation (37.2 %) followed by medium canopy situation (33.0 %) and light canopy situation (17.3 %). The level of reduction under canopy situations was higher in case of belowground biomass when compared to the aboveground biomass. Standing tree biomass of *Acacia tortilis* increased with the increase in tree density. Highest mean total biomass was recorded at microsite 4 (93.3 DM t/ha) followed by microsite 3 (82.8 DM t/ha) and microsite 2 (71.2 DM t/ha). The production of aerial biomass to total biomass was highest at microsite 4 (85.0 %) closely followed by microsite 3 (83.8 %) and microsite 2 (83.2 %). Similarly, the biomass obtained as a result of lopping also increased with the increase in tree density. Highest total lopped biomass was recorded at microsite 4 (0.47 DM t/ha) followed by microsite 3 (0.26 DM t/ha) and microsite 2 (0.15 DM t/ha).

Total system productivity (aboveground + belowground) increased with the increase in tree density. Highest total system productivity was reocrded at microsite 4 (10.93 DM t/ha/yr) followed by microsite 3 (10.34 DM t/ha/yr), microsite 2 (9.73 DM t/ha/yr) and microsite 1 (4.82 DM t/ha/yr). Thus total system productivity under silvopastures increased from 2.02 to 2.27 times when

compared to only pasture land use system. The top feed maintained much higher level of crude protein (11.8 %) when compared to pasture component (3.9 %).

In *Acacia tortilis*, the litter fall was mostly concentrated during January to June (93%). Peak litter production was recorded during May closely followed by April at all the microsites. Leaves contributed about 72 per cent of the total litter fall receipt during both the years. It was followed by the branch litter (23 %) and miscellaneous litter (4 %). At this growth stage, total litter production varied from 3.00 to 5.05 t/ha/yr with the increase in tree density.

The various tree parts maintained higher range of nitrogen concentration when compared to pasture components. The concentration of all the nutritents *viz*., N, P, K and Ca in leaf litter was lower when compared to standing leaf.

The accumulation of all the nutrients was higher in aboveground parts. The accumulation of nutrients increased from microsite 2 to micrsoite 4, primarily on account of more total tree biomass with increase in tree density. Highest accumulation of nitrogen was in branch followed by root, pod, bole and leaf. However, highest accumulation of phosphorus, potassium and calcium was in branch followed by root, bole, pod and leaf. Highest accumulation of nutrients was registered in case of nitrogen (536-699 kg/ha) followed by calcium (292-380 kg/ha), potassium (168-219 kg/ha) and phosphorus (42-53 kg/ha).

Return of nitrogen, through litter fall ranged from 43.6 to 73.1 kg/ha with the increase in tree density. Similar returns in case of phosphorus, potassium and calcium were in range of 3.9 to 6.4 kg/ha, 9.3 to 15.8 kg/ha and 47.2 to 79.8 kg/ha, respectively.

Tree leaf litter was found to be the most important for nutrient release in silvopastures. Trend of increased rate of decomposition was observed with the increase in tree density. As a result of mass loss the concentration of all the nutrients decreased with time. Maximum reduction was recorded in case of potassium (73 %) followed by calcium (65 %), nitrogen (60 %) and phosphorus (58 %). The higher rate of decomposition in rainy season was attributed to

suitable temperature and moisture condition for the activity of decomposers and frequent rain sources for leaching of water soluble substances.

Nutrient budgets for nitrogen, phosphorus, potassium and calcium were prepared for the three silvopasture microsites. The per cent nutrient lock up in above + belowground (of total soil pool) varied from 2.50 to 3.20 per cent in case of nitrogen, 6.30 to 7.90 per cent in case of phosphorus, 0.27 to 0.34 per cent in case of potassium and 0.34 to 0.43 per cent in case of calcium. The per cent nutrient lock up increased with the increase in tree density. Similarly, per cent of potential recyclable nutrients through leaf litter (of aboveground nutrients) varied from 9.1 to 11.6 per cent in case of nitrogen, 12.9 to 14.6 per cent in case of phosphorus, 6.0 to 8.3 per cent in case of potassium and 17.2 to 22.9 per cent in case of calcium.

An increase in soil fertility parameters *viz.*, available nitrogen (9.3 %), total potassium (9.1 %), organic carbon (8.8 %), organic matter (4.1 %) and total calcium (2.3 %) was registered during the study period. Generally, higher level of nutrients under trees after two years may be due to litter addition and their decay. Root decay may be another mechanism in this respect. Soil fertility enhancement through litter/root decomposition and nutrient cycling in silvopastures involve complex and long term processes that require long term studies. However, enrichment of soil in almost all the nutrients at the study site where *Acacia tortilis* trees approached the canopy closure stage, indicated potential role of this tree species in ameliorating soil fertility in medium to long term.

BIBLIOGRAPHY

BIBLIOGRAPHY

Adu-Anning, C., Anglaaere, L. C. N. and Nwoboshi, L. C. 1995. Growth, energy yield and nutrient uptake of some fuelwood species in the Sudan Savanna of Ghana. *J. Tree Sci.*, 14: 23-31.

Aggarwal, R. K., Gupta, J. P., Saxena, S. K. and Muthana, K. P. 1975. Studies on soil physico-chemical and ecological changes under twelve year old five desert species of West Rajasthan. *Indian For.*, 102: 863-872.

Ahuja, L. D., Verma, C. M., Sharma, S. I. and Lamba, T. R. 1978. Range management studies on the contribution of ground storey (grass) in afforested areas in arid region. *Ann. Arid Zone*, 17: 304-331.

Alexander, M. 1977. *Introduction to Soil Microbiology.* Wiley Eastern Limited, New Delhi: 467 p.

Alpizar, L. H. W., Fassbender, Heuveldop, H. P. and Enriquez, G. 1986. Modelling agroforestry systems of Coco (*Theobroma cocoa*) with Laurel (*Cordia alliodora*) and Poro (*Erythrina poeppigiana*) in Costa Rica. I. Inventory of organic matter and nutrients. *Agroforestry System*, 4: 175-189.

Ambast, R. S. 1988. Studies on biomass productivity of some tropical grazing lands and plantation forests. *In: Rangelands - Resources and Management* (eds P. Singh and P. S. Pathak). RMSI, Jhansi: 38-44.

Anderson, M. C. 1964. Light relations of terrestrial plant communities and their measurement. *Biol. Rev.*, 39: 425-486.

Andriesse, J. P. and Schelhaas, R. M. 1977. A monitoring study of nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia. II. Nutrient stores in biomass and soil results of baseline studies. *Agriculture, Ecosystems and Environment*, 19: 255-310.

Ani, A., Tajuddin, I., and Chang, D. T. 1985. Sheep rearing under rubber. *Proceeding of The Ninth Annual Conference of The Malaysian Society of Animal Production.* University Pertanian Malaysia, Serdang, Malaysia.

Anonymous 1988. *Annual Report on AICRP-AF*, G. B. Pant University of Agri. & Tech., Pantnagar: 33 p.

Applegate, G. E., Gilmour, D. A. and Mohns, B. 1988. The use of biomass equations in the management of forests for fuel wood and fodder production. *Commonwealth Forestry Review*, 67: 141-148.

Arya, S. P. 1995. Forage and fodder production through agroforestry. *In: Advances in Agroforestry* (ed. L. K. Jha). APH Publishing Corporation, New Delhi: 101-135.

Bath, E. 1980. Soil fungal biomass after clear cutting of a pine forest in central Sweden. *Soil Biol. Biochem.* 12: 495-500.

Bawa, R. 1992. Nutrient dynamics and budgets in Himalayan grassland. II. Phosphorus. *Range Mgmt. & Agroforestry,* 13: 115-130.

Baxi, M. R. 1985. Some forage production studies under silvipasture system and its impact in Andhra Pradesh. *Term paper for partial fulfilment of the requirement of national diploma on Forage Production and its Utilization,* IGFRI, Jhansi:18

Bell, T. I. W. 1973. Erosion in Trinadad teak plantation. *Commonwealth Forestry Rewiew*, 52: 223-233.

Berendse, F. 1979. Competition between plant population with different rooting depths. I. Theoritical consideration. *Oceologia (Berl.)*, 43: 19-26.

*Bhatnagar, S. 1968. Ecological studies of some forests of Sagar with special reference to litter and ground flora. *Ph. D. Thesis*. Sagar University, Sagar.

Bhimaya, C. P., Kaul, R. N. and Ganguli, B. N. 1964. Studies on lopping intensities of *Prosopis spicigera. Indian For.*, 90: 19-23.

Bhola, N. 1995. Studies on relative growth performance and soil enrichment potential of some nitrogen fixing trees. *M. Sc. Thesis*, Dr. Y. S. Parmar University of Hort. and For., Solan (HP).

Bhumbla, D. R. 1992. Forestry and Land Use Policies. *In: Status of Indian Forestry: Problems and Perspectives.* (ed. P.K. Khosla). Indian Society of Tree Scientist (ISTS), Solan: 51-68.

Billore, S. K. and Mall, L. P. 1975. Nutrient composition and inventory in a tropical grassland. *Plant & Soil*, 45: 509-520.

Binkley, D. 1986. *Forest Nutrition Management.* John Wiley & Sons, New York: 290 p.

Bist, P. S. and Kediyal, V. K. 1989. Performance of some grasses for soil stabilization in temperate region of Garhwal. *Indian J. Range Mgmt.*, 10: 91-96.

Bor, N. L. 1960. *The grasses of Burma, Cylon, India and Pakistan.* Pergaman Press, London: 116 p.

Bormann, F. H., Likens, G. E. and Mellello, J. M. 1977. Nitrogen budget for an aggrading northern hardwood ecosystem. *Science*, 196: 981-983.

Borough, C. J. 1984. Diversification in forest. *In: Integrating agriculture and forestry* (eds K.M.W. Howes and R.A. Rummery), Natraj Publishers, Dehra Dun: 24-31.

Bray, J. K. and Gorham, E. 1964. Litter production in forest of the world. *Adv. Ecol. Res.*, 2: 101-157.

Bray, J. R. 1963. Root production and estimation of net productivity. *Can. J. Bot.*, 41: 65-72.

Brinson, M., Bradshaw, H. P., Holmes, R. N. and Elkins, J. B. 1980. Litterfall, stemflow and throughfall nutrient fluxes in an alluvial swamp forest. *Ecology*, 61: 827-835.

Bruinjnzel, L. A. 1991. Nutrient input-output budgets of tropical forest ecosystems: A review. *Journal of Tropical Ecology*, 7: 1-24.

Castellanos, J., Mass, M. and Kummerow, J. 1991. Root biomass of a dry deciduous tropical forest in Mexico. *Plant & Soil*, 131: 225-228.

Chakraborty, R. N. and Chakraborty, D. 1989. Changes in soil properties under *Acacia auriculiformis* plantations in Tripura. *Indian For.*, 115: 272-273.

Champion, H. G. and Seth, S. K. 1968. *A Revised Survey of Forest Types of India.* Manager of Publications, New Delhi: 195 p.

Chandrasekharaiah, A. M. and Prabhakar, A. S. 1987. Growth and its analysis of tree species in agroforestry systems. *Journal of Farming Systems*, 3: 17-21.

Chatterjee, B. N. and Das, P. K. 1989. Silvipasture and Agro-Forestry. *Forage Crop Production: Principles and Practices.* Oxford and IBH Publication Co. Pvt. Ltd., New Delhi: 80-92.

Chaturvedi, O. P. and Saxena, A. K. 1992. Composition, yield and diversity of grazing land vegetation under pine forest in central Himalaya. *Range Mgmt. & Agroforestry*, 13: 97-106.

Chaturvedi, O. P., Saxena, A. K. and Singh, J. S. 1988. Structural and functional analysis of grazing land under pine forest in central Himalaya. *Oecologica – Oecologica Generalis*, 9: 167-178.

Chaubey, O. P., Prasad, R. and Misra, G. P. 1988 Litter production and nutrient return in teak plantations and adjoining natural forests in Madhya Pradesh. *J. Trop. For.*, 4: 240-255.

Cole, C. V., Innis, G. S. and Stewart, J. W. B. 1977. Simulation of phosphorus cycling in semi arid grassland. *Ecology*, 58: 1-15.

Cole, D. W., Gessel, S. P. and Dice, S. F. 1968. Distribution and cycling of nitrogen, phosphorus, potassium and calcium in second growth Douglas Fir ecosystem. *In: Primary Productivity and Mineral Cycling in Natural Ecosystems* (ed. H. E. Young). University of Maine Press, Oronto: 197-232.

Corlett, J. E. and Ong, C. K. 1989. Microclimatic modifications in intercropping and alley cropping systems. *In: Meterology and Agroforestry* (eds W. S. Reifsnyder and T. O. Darnhofer). ICRAF, Nairobi (Kenya): 419-430.

Cormforth, I. S. 1970. Leaf fall in a tropical rain forest. *Journal of Applied Ecology*. 7: 603-608.

CSIR 1950. *The Wealth of India* (Vol. II), Council of Scientific and Industrial Research, New Delhi: 151 p.

CSIR 1985. *The Wealth of India*, Raw Materials, Vol 1A, Council of Scientific and Industrial Research, New Delhi: 46p.

Cunningham, R. K. 1963. The effect of clearing a tropical forest soil. *J. Soil Sci.*, 14: 334-345.

Dabadghao, P. M. and Sankarnarayan, K. A. 1973. *The Grass Cover of India.* ICAR, New Delhi.

Dadhich, L. K. 1979. Nutrient distribution in few dominant tree species of Jhamarkhtra. I. Foliar analysis. *Acta Ecol.,* 1: 57-63.

Dagar, J. C., Singh, N. T. and Singh, G. 1994. Agroforestry options for degraded and problematic soils of India. *In: Agroforestry Systems for Sustainable Land Use* (eds Panjab Singh, P. S. Pathak and M. M. Roy). Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi: 96-120.

Dalal, S. S. 1992. Forestry - past, present, future. *In: Status of Indian Forestry - Problems and Perspectives* (ed. P. K. Khosla). ISTS, Solan: 16-25.

Deb Roy, R. 1986. Studies on some aspects of renewable energy (fuel) and pasture production in an ecosystem of *Albizia procera* Benth. and *Albizia lebbek* (L.) Benth. with grass and legume. *Ph.D. Thesis*, Jiwaji University, Gwalior.

Deb Roy, R. 1988. Strategy for increased forage production through silvipastoral system. *In: Forage Production in India* (ed. P. Singh). RMSI, Jhansi: 164-169.

Deb Roy, R. 1988 a. Biomass production potantial of *Albizia lebbek* under silvipastoral system. *In: Advances of Forestry Research in India* (ed. Ram Prakash). International Book Distributors, Dehra Dun: 33-46.

Deb Roy, R. 1988 b. The growth and aerial biomass production of *Albizia procera* under silvipastoral system. *In: Rangelands - Resources and Management* (eds. P. Singh and P. S. Pathak). RMSI. Jhansi: 338-342.

Deb Roy, R. 1990. Silvipasture production systems - Present status and future prospects in India. *Lecture for the one month training programme on "Agroforestry Forage Production and Animal nutrition" for scientists of SAU's sponsored by ICAR under its NARP*, IGFRI, Jhansi, December 26, 1989- January 25, 1990.

Deb Roy, R. 1990 a. Biomass production potential of fodder-cum-fuel trees under silvipastoral systems. *In: Promotion of Fodder and Fuelwood Trees* (eds N. G. Hedge, L. L. Relwani and V. D. Kelkar). BAIF, Pune: 70-76.

Deb Roy, R. 1994. Agroforestry- Sustainable agriculture and environment. *In: Natural Resource Management for Sustainable Agriculture and Environment* (ed. Prof. D. L. Deb), Angkor Publishers, New Delhi: 377-386.

Deb Roy, R., and Gupta, S. K. 1984. Silvipastoral studies in fodder-cum-fuel trees. *Annual Report*, IGFRI, Jhansi: 146-150.

Deb Roy, R., Das, B. and Bhati, G. N. 1975. Studies on effect of intensity and interval of defoliation on forage production of *Dicanthium annulatum* (Forsk.) Stapf. *Ann. Arid Zone,* 14: 13-20.

Deb Roy, R., Patil, B. D. and Pathak, P. S. 1978. Silvipastoral farming for amelioration and increased productivity for arid and semi-arid region. *In: Proceeding of the International Symposium on Arid Zone Research and Development.* CAZRI, Jodhpur: 531 p.

Deb Roy, R., Patil, B. D., Pathak, P. S. and Gupta, S. K. 1980. Forage production of *Cenchrus ciliaris* and *Cenchrus setigerus* under silvipastoral system. *Indian J. Range Mgmt.,* 1: 113-120.

Deb Roy, R., Patil, B. D., Pathak, P. S. and Gupta, S. K. 1982. Growth of *Acacia tortilis* in a silvipastoral system. *Indian J. Range Mgmt.*, 3: 45-51.

Desale, J. S., Patil, S. K., Pisal, A. A. and Amrutsagar, V. M. 1990. Tree biomass production optimization strategies. *In: Silvipastoral Systems in India* (eds P. S. Pathak and Panjab Singh), RMSI, Jhansi: 109-114.

Dhyani, S. K., Narain, P. and Singh, R. K. 1990. Studies on root distribution of five multipurpose tree species in Doon valley, India. *Agroforestry Systems,* 12: 149-161.

Dommergues, Y. R. 1987. The role of biological fixation in agroforestry. *In: Agroforestry : A Decade of Development* (eds. H. A. Steppler and P. K. R. Nair). ICRAF. Nairobi (Kenya): 245-271.

Egunjobi, J. K. 1974. Litterfall and mineralisation in a teak (*Tectona grandis*) stand. *Oikos*, 25: 222-226.

FAO. 1978. China: Forestry Support for Agriculture (Forestry Paper 12). Food and Agriculture Organisation, Rome.

Field, C. and Mooney, H. A. 1986. The photosynthesis nitrogen relationship in wild plants. *In: On the Economy of Plant Form and Function* (ed. P. J. Givnish). Cambridge University Press, Cambridge (UK): 25-55.

FSI 1987. *The State of Forest Report.* Forest Survey of India, Dehra Dun.

Ganguli, B. N., Kaul, R. N. and Nambiar, K. T. N. 1964. Preliminary studies on a few top feed species. *Ann. Arid Zone*, 3: 33-37.

George, M. 1979. Organic productivity and nutrient cycling in *Eucalyptus* hybrid plantation. *Ph.D. Thesis*, Meerut University, Meerut.

George, M. 1982. Litter production and nutrient return in *Eucalyptus* hybrid plantations. *Indian For.*, 108: 253-260.

George, M. 1986. Nutrient uptake and cycling in an young *Eucalyptus* hybrid Plantation. *Myforest*, 22: 19-26.

George, S. J. and Mohan Kumar, B. 1998. Litter dynamics and soil fertility improvement in silvopastoral systems of the humid tropics of southern India. *Intl. Tree Crops J.*, 9: 267-282.

Ghosh, R. C. 1980. Silvipastoral systems: the concepts old and new. *Proc. FAO/DANIDA Training Course on Sand Dune Stabilization, Shelterbelt and Afforestation in the Dry Zones.* CAZRI, Jodhpur: 232-262.

Ghosh, S. P. (ed.) 1991. *Agroclimatic Zone Specific Research.* Indian council of Agricultural Research, New Delhi: 539 p.

Gill, A. S. 1986. A fuel/fodder production system using *Sesbania grandifolia. Nitrogen Fixing Tree Research Reports*, 4: 14-15.

Gill, A. S. and Deb Roy, R. 1992. Agro-Forestry Research Situation in India. *Agriculture Situation in India,* 8: 345-354.

*Gill, H. S. 1985. Studies on the evaluation of selected tree species for their tolerance to sodicity and mechanical impedance in a highly sodic soil with particular reference to root growth behaviour. *Ph. D. Thesis*, Kurukshetra University, Kurukshetra.

Gill, H. S. and Abrol, I. P. 1987. Amelioration of salt affected soils by trees. *In: Amelioration of Soils by Trees.* Commonwealth Science Council. The Commonwealth Secretariat, London: 43-53.

Girolkar, A. K. and Naik, M. L. 1987. Leaf litter fall in an artificial and natural forest of Lakha and Bhudeopur, Raigarh, India. *J. Curr. Biol. Sci.*, 4: 77-83.

GOI 1987. *Livestock Census Report.* Directorate of Economics and Statistics, Ministry of Agriculture, Govt. of India, New Delhi.

Golley, F. B. 1978. Gross and net primary production and growth parameters. *In: Tropical Forest Ecosystems – A State of Knowledge Report* (UNESCO/UNEP/FAO). UNESCO, Paris: 233-248.

Gorrie, R. M. 1937. Tree lopping on a permanent basis. *Indian For.*, 63: 29-31.

Gour, J. P. and Pandey, H. N. 1978. Litter production in two tropical deciduous forest communities at Varanasi, India. *Oikos,* 30: 570-575.

Griffiths, J. F. 1985. Climatology. *In: Handbook of Applied Meteorology* (ed. D. D. Houghton). John Wiley and Sons, New York: 62-132.

Gupta, R. K. and Saxena, S. K. 1972. Distribution and growth of *Sehima nervosum* (Rottl.) Stapf. in Rajasthan. *Indian J. Agric. Res.,* 6: 151-158.

Gupta, S. K. 1997. Dry matter dynamics and mineral budget of *Prosopis juliflora* (Swartz) de Witt. plantation on degraded lands. *Ph. D. Thesis*, Shri Chatrapati Sahooji Maharaj University, Kanpur: 118 p.

Gupta, S. K. and Pathak, P. S. 1994. Productivity of *Faidherbia albida* (Del.) A. Chev. in silvipastoral system on Alfisols in Central India. *In: Agroforestry Systems for Degraded Lands* (eds Panjab Singh, P. S. Pathak and M. M. Roy). Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi: 720-728.

Gupta,S. R. and Singh, J. S. 1977. Decomposition of litter in tropical grassland. *Pedobiologia*, 17: 330-333.

Gurumurti, K., Kimthos, M. K., Raturi, D. P. and Rawat, J. S. 1984. Biomass production and energy conversion efficiency by *Eucalyptus* in energy plantation. *Indian For.*, 110: 150-170.

Gurumurti, K., Raturi, D. P. and Bhandari, H. C. 1984 a. Biomass production in energy plantation of *Prosopis juliflora. Indian For.*, 110: 879-894.

Hagos, M., Samuelsson, G., Kenne, L. and Modawi, B. M. 1987. Isolation of smooth muscle relaxing 1,3-diaryl-propan-2-ol derivatives from *Acacia tortilis*. *Planta Medica,* 53: 27-31.

Hazella, D. B. 1967. Effect of grazing intensity on plant composition, vigour and production. *J. Range Mgmt.*, 20: 249-252.

Hazra, C. R. 1981. Physical condition of soils of Bundelkhand region – limitations and potentialities. *Indian J. Range Mgmt.*, 2: 17-22.

Hazra, C. R. 1985. Forage and seed yield of crops under agroforestry production system - radiation and temperature relation. *J. Agronomy and Crop Sci.*, 155: 186-192.

Hazra, C. R. 1990. Revitalization of degraded land resources through silvipastoral system for herbage production. *In: Silvipasture Systems in India* (eds P. S. Pathak and Panjab Singh). RMSI, Jhansi: 81-86.

Hazra, C. R. and Patil, B. D. 1986. Forage production under silvipastoral system - light and temperature interaction. *Indian J. Range Mgmt.*, 7: 33-36.

Hazra, C. R. and Tripathi, S. B. 1986. Soil properties, micrometeorological parameters, forage yield and phosphorus uptake of berseem as influenced by phosphate application under agroforestry system of production. *J. Agronomy & Crop Sci.*, 145-152.

Hazra, C. R. and Tripathi, S. B. 1989. Performance of oat genotypes under different tree covers and in open situation. *Agricultural Science Digest* Karnal, 9: 146-148.

Hellemers, H., Horton, J. S., Juhren, G. and O'Keefe, J. 1955. Root system of some chaporral plants in southern California. *Ecology*, 36: 667-678.

Hosur, G. C., Dasog, G. S. and Satyanarayan, T. 1997. Litter production and nutrient return of different tree species under plantation conditions. *Indian J. For.*, 20 (3): 231-235.

Igboanugo, A. B., Omijeh, J. E. and Adegehin, J. O. 1986. Pasture and floristic composition of different *Eucalyptus* species plantation in some parts of Northern Guinea Savanna Zone of Nigeria. *J. Ecology*, 79: 257-267.

Isichel, A. O. and Muoghalu, J. I. 1992. The effects of tree canopy cover and soil fertility in a Nigerian Savanna. *J. Trop. Ecol.*, 9: 329-338.

Ismail, T. 1986. Integration of animals in rubber plantations. *Agroforestry Systems*, 4: 55-66.

Jackson, J. E. 1989. Tree and crop selection and management to optimize overall system productivity especially light utilization in agroforestry. *In: Meteorology and Agroforestry* (eds W. S. Reifsnuder and T. O. Darnhofer). ICRAF, Nairobi (Kenya): 163-173.

Jackson, M. L. 1973. *Soil Chemical Analysis*. Prentice-Hall of India Pvt. Ltd., New Delhi: 498 p.

Jamaludheen, V. and Mohan Kumar, B. 1999. Litter of multipurpose trees in Kerala, India : variations in the amount, quality, decay rates and release of nutrients. *For. Ecol. Mgmt.*, 115: 1-11.

Jha, L. K. (ed.) 1995. *Advances in Agroforestry.* APH Publishing Corporation, New Delhi: 669 p.

Jordan, C. F. 1985. *Nutrient Recycling in Tropical Forest Ecosystem.* John Wiley & Sons, New York: 194 p.

Joshi, S. K. 1993. Leaf litter in a tropical deciduous forest from Orissa. *J. Trop. For.*, 9: 12-20.

Kalla, J. C., Gyan Chand, Vyas, D. L. and Gehlot, N. S. 1978. Techno-economic felling cycle for selected energy plantation species in arid zone of western Rajasthan. *Ann. Arid Zone*, 17: 42-51.

Kanodia, K. C. 1981. Studies on the ecology of grasses and grassland in Jhansi district (Uttar Pradesh). *Ph. D. Thesis*. Jiwaji University, Gwalior.

Kapoor, K. S. and Singh, R. 1992. Concentration, standing state and cycling of potassium in soil vegetation components of temperate grasslands in Shimla hills, Himanchal Pradesh. *Range Mgmt. & Agroforestry*,13:1-10.

Katewa, S. S. and Tiagi, Y. D. 1991. Productivity potential of grazing lands of Udaipur district (Rajasthan). *Range Mgmt. & Agroforestry*, 12: 53-59.

*Kaul, O. N. 1980. *Forest Production on Sand-dunes with Special Reference to India*. Paper presented to FAO/DANIDA Training Course on Sand Dune Stabilization, Shelter-belts and Afforestation in Dry Zones.

Kaul, O. N., Sharma, D. C. and Tandon, V. N. 1983. Biomass distribution and productivity in a poplar paIntation. *Indian For.*, 109: 822-828.

Khan, T. A., Pathak, P. S., Deb Roy, R. and Gupta, S. K. 1993. Prediction models for volume of timber and total wood biomass in *Hardwickia binata* grown under silvipastoral system. *J. Tree Sci.*, 12: 73-76.

*King, K. F. S. and Chandler, M. T. 1978. *The Waste Lands.* ICRAF, Nairobi.

Konwar, G. R., Osman, M. and Singh, R. P. 1989. Fodder and fuelwood production system for sandy loam soils of semi-arid Hyderabad. *In: Promotion of Fodder and Fuelwood Trees* (eds N. G. Hedge, L. L. Relwani and V. D. Kelkar), BAIF, Pune: 77-82.

Kushalappa, K. A. 1987. Productivity of Mysore Gum (*Eucalyptus* hybrid) under different ecosystems in Karnataka. *Myforest*, 23: 217-226.

Kushalappa, K. A. 1988. Comparative biomass of *Acacia auriculiformis* and *Leucaena leucocephala* trees from moist regions of Karnataka. *Myforest*, 24: 12-15.

Lal, J. B. 1990. Deforestation - Causes and Control. *In: Status of Indian Forestry Problems and Perspectives* (ed. P. K. Khosla). Indian Society of Tree Scientist (ISTS), Solan: 33-49.

Laurie, M. V. 1945. *Fodder Trees in India.* Ind. For. Leaf l. 82 (Silv.). FRI, Dehra Dun: 17 p.

Leith, H. 1970. Phenology in productivity studies. *In: Analysis of Temperate Forest Ecosystems (Ecological Studies Vol. 1)* (ed. D. E. Reichle). Springer-Verlag, Heudelberg: 29-56.

*Lundgren, B. 1978. Soil conditions and nutrient recycling under natural and plantation forests in Tanzania highlands. *Report on Forest Ecology and Forest Soils, No. 31.* Department of Forest Soils, Swedish University of Agricultural Sciences, Uppsala (Sweden).

Lundgren, B. 1979. Research strategy for soils in agroforestry. *In: Soil Research in Agroforestry* (eds H. O. Mongi and P. A. Huxley). ICRAF, Nairobi (Kenya).

Mac Dicken, K. G. 1994. *Selection and Management of Nitrogen Fixing Trees.* Food and Agriculture Organization, Rome and WIIAD, Arlington (USA): 149-151.

Mac. Dicken, K. G., Wolf, G. V. and Briscoe, C. B. (eds) 1991. *Standard Research methods for Multipurpose Trees and Shrubs.* WIIAD, Arlington (USA) : 91p.

Macfadyen, A. 1963. The contribution of microfauna to total soil metabolism. *In: Soil Organisms* (eds. J. Docksem and J. Van Der Drift). North Holland Publishing Co., Amsterdam.

Madge, D. S. 1965. Leaf and litter disappearance in a tropical forest. *Pedobiologia*, 5: 273-288.

Mahadevan, N. P. 1991. Phenological observations of some forest tree species as an aid to seed collection. *J. Trop. For.*, 7: 243-247.

Mal, B. and Roy, M. M. 1999. Production potential of forages in drylands. *In: Sustainable Alternate Land Use Systems For Drylands* (eds R. P. Singh and M. Osman). Oriental Enterprises, Dehra Dun: 171-196.

Malik, K. P. S. and Prakash, O. 1993. Litter dynamics and nutrient cycling in some multipurpose tree species under agroforestry conditions. *In: Agroforestry in 2000 AD for the Semi-arid and Arid Tropics* (eds A. S. Gill, R. Deb Roy and A. K. Bisaria). NRCAF, Jhansi: 127-128.

Mall, L. P. and Billore, S. K. 1974. Production relations with density and basal area in a grassland community. *Geobios*, 1: 84-86.

Mannikar, N. D. 1981. Soils of Bundelkhand region – problems and prospects. *Indian J. Range Mgmt.*, 2: 9-16.

Mc Shane, M. C., Charlile, D. W. and Hinds W. T. 1983. The effect of collector size on forest litter fall collection and analysis. *Can. J. For. Res.*, 13: 1037-1042.

Mengel, K. and Kirkby, E. A. 1982. *Principles of Plant Nutrition*. International Potash Institute, Berne: 655 p.

Michael, G. B. 1986. Concept of resourcesharing in agroforestry systems. *Agroforestry Systems*, 4: 191-203.

Miller, D. H. 1959. Transmission of insolation through pine forest canopy as it affects the melting of snow. *Schweiz Anst. f. forstl. Versuchusw. Mitt.*, 35: 57-59.

Miller, D. R. 1993. Microclimate in agroforestry. *In: Agroforestry in South Asia: Problems and Applied Research Perspectives* (eds W. R. Bentley, P. K. Khosla and K. Seckler). Winrock International, Arlington (USA) and Oxford & IBH Publishing Co., New Delhi: 103-114.

Minson, D. J. 1990. The chemical composition and nutritive value of tropical grasses. *In: Tropical grasses* (eds P. J. Skerman and F. Riveros), FAO, Rome: 163-180.

Mishra, L. P. and Bhatt, R. K. 1990. Light transmission, canopy temperature and productivity of grasses under silvipastoral system. *In: Silvipastoral Systems in India* (eds P. S. Pathak and Panjab Singh). RMSI, Jhansi: 179-182.

Mishra, M. K. and Nisanka, S. K. 1997. Litterfall, decomposition and nutrient release in *Casurina equisetifolia* plantations on the sandy coast of Orissa, India. *Tropical Ecology*, 38: 109-119.

Misra, L. C. 1979. Nitrogen cycling in grasslands at Kanpur. *Plant & Soil*, 53: 361-371.

Misra, L. P. and Bhatt, R. K. 1992. Light transmission, canopy temperature and productivity of grasses under silvipastoral system. *In: Silvipastoral Systems in India* (eds P. S. Pathak and P. Singh). RMSI, Jhansi: 179-186.

Mitchel, J. W. 1936. Effect of atmospheric humidity on rate of carbon fixation by plants. *Bot. Gaz.*, 98: 87-104.

Montagnini, F. and Sancho, F. 1994. Nutrient budgets of young plantations with native trees: Strategies for sustainable management. *In: Forest Resources and Wood based Biomass Energy as Rural Development Assets* (eds W. R. Bentley and M. M. Gowen). Winrock International (USA) and Oxford & IBH Publishing Co., New Delhi: 213-233.

Montagnini, F., Ramstad, K. and Sancho, F. 1993. Litter fall, litter decomposition and the use of mulch of four indigenous tree species in the Atlantic Lowlands of Costa Rica. *Agroforestry Systems*, 23: 39-61.

Montagnini, F., Sancho, F., Ramstad, K. and Stijfhoon, E. 1991. Multipurpose trees for soil restoration in the humid lowlands of Costa Rica. *In: Research on Multipurpose Trees in Asia. Proceeding of an International Symposium (November 19-23, 1990, Los Banos, Philippines)* (eds D. A. Taylor and K. G. Mac Dicken). WIIAD, Bangkok: 41-58.

Mukherji, A. K. 1998. Sustainable bio-energy (fuel wood) supply for meeting rural needs - policy options. *Convention and Symposium on Sustainable Biomass Production in Rural Development*, March 17-18, 1998, ICAR, New Delhi.

Murphy, P. G. and Lugo, A. E. 1986. Structure and biomass of a subtropical dry forest in Puerto Rico. *Biotropica*, 18: 89-96.

Muthana, K. D. and Arora, G. D. 1980. *Acacia tortilis* (Forsk.) Hayne - A promising fast growing tree for Indian arid zones. *Technical Bulletin No. 5*. CAZRI, Jodhpur: 19 p.

Muthana, K. D., Meena, G. L., Bhatia, N. S. and Bhatia, O. P. 1984. Root system of desert tree species. *Myforest*, 20: 27-38.

Nagar, S. 1992. A short history of forestry in India. *In: Status of Indian Forestry - Problems and Perspectives* (ed. P. K. Khosla). ISTS, Solan: 7-13.

Naik, M. L. and Srivastava, B. K. 1985. Leaf litter fall in forests of Surguja, Madhya Pradesh. *J. Trop. For.*, 1: 140-144.

Nair, P. K. R. 1983. Agroforestry with coconuts and other plantation crops. *In: Plant Research and Agroforestry* (ed. P. A. Huxley). ICRAF, Nairobi (Kenya): 79-102.

Nair, P. K. R. 1989. The role of trees in soil productivity and protection. *In: Agroforestry Systems in the Tropics* (ed. P. K. R. Nair). ICRAF, Nairobi and Kluwer Academic Publishers, Dordoecht, (the Netherlands) : 567-589.

NAS 1980. *Firewood Crops - Shrubs and Tree Species for Energy Production.* National Academy of Sciences, Washington DC: 236p.

Natar, L. 1972. Influence of mineral nutrients on photosynthesis in higher plants. *Photosynthetica*, 6: 80-99.

Negi, M. S., Tondon, V. N. and Rawat, H. S. 1995. Biomass and nutrient distriburion in young Teak (*Tectona grandis* Linn. F.) plantations in Tarai region of Uttar Pradesh. *Indian For.*, 121: 455-464.

Neil, R. V. and De Angelis, D. L. 1981. *Dynamic Properties of Forest Ecosystem* (ed. D. E. Ruichle). Cambridge University Press, New York: 499 p.

New Bould, P. J. 1967. Methods of estimating Primary Production of Forests. *IBH Handbook No. 2*. Blackwell Scientific Publication, Oxford (UK): 172 p.

Nitant, H. C. and Tiwari, S. P. 1991. Soil resources appraisal for land use planning in Bundelkhand Region. *J. Soil & Water Cons.* 35:17-25.

Njoku, E. 1963. Seasonal periodicity in the growth and development of some forest trees in Nigeria I. Observations on mature trees. *Journal of Ecology*, 51: 617-624.

Norton, B. W. and Poppi, D. P. 1995. Composition and nutritional attributes of Pasture legumes. *In: Tropical Legumes in Animal Nutrition* (eds J. P. F. D'Mello and C. Devendra). CAB International, Walling Ford, Oxon (UK): 23-47.

NWDB 1990. *Report on Fodder Demand and Supply.* National Wasteland Development Board, Govt. of India, New Delhi.

Nwoboshi, L. C. 1980. Nitrogen cycling in teak plantation ecosystem in Nigeria. *In: Nitrogen Cycling in West African ecosystems* (ed. T. Rasswall). SCOPE/UNEP. International Nitrogen Units, Royal Swedish Academy of Sciences, Stockholm: 353-361.

Olsen, S. R., Cole, C. V., Watanbe, F. S. and Dean, L. A. 1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. *USDA Circular*: 9-39.

Olson, J. S. 1963. Energy Storage and the balance of producers and decomposers in ecological systems. *Ecology*, 44: 322-331.

Ong, C. K., Odongo, J. C. W., Marshal, F. and Black, C. K. 1991. Water use by trees and crops - five hypothesis. *Agroforestry Today*, 3: 7-10.

Pal, M. and Raturi, D. P. 1989. Biomass production and the relationship between growth behaviour and organic matter allocation pattern of *Acacia nilotica* grown in an energy plantation. *Indian J. For.*, 12: 13-16.

Pandey, K. C. and Shivanker, V. J. 1994. Pest of fodder trees and their management. *In: Forest Entomology* (eds L. K. Jha and P. K. Sen Sherma) Asish Publishing House, New Delhi: 149-163.

Pandey, P. K. and Sharma, S. C. 1988. Litter nutrient dynamics of some plantations at New Forest, Dehradun (India). *J. Trop. For.*, 4: 339-349.

Pandeya, S. C. 1974. Dynamics of primary productivity of grazing land and forest ecosystems in western India. *Proc. First Intl. Cong. Ecol.* : 46-51.

Pandeya, S. C. 1988. *Status of Indian Rangelands*. RMSI, Jhansi: 213 p.

Pandit, B. R. 1984. Productivity of *Dicanthium annulatum* (Forsk.) Stapf. in grazing land at Bhavnagar, Gujarat. *Indian J. Range Mgmt.*, 5: 11-14.

Pandit, B. R., Subramanyam, S. V. S. and Raghavendra Rao, K. V. 1993. Leaf litter production of the dry deciduous forest ecosystem of Eastern Gir (Gujarat). *Indian For.*, 119: 375-380.

Pandya, S. M. and Sidha, V. K. 1989. Seasonal variation in plant biomass, primary production in grazing lands of Kutch district (Gujarat), India. *Indian J. Range Mgmt.*, 10: 15-32.

Pant, S. C. and Tewari, S. C. 1992. Litter fall and litter decomposition in a montane oak forest of Garhwal Himalaya. *Tropical Ecology*, 30: 1-22.

Paroda, R. S., Muthana, K. D. and Sharma, S. K. 1977. Silvipastoral studies. *Annual Report*, CAZRI, Jodhpur: 71 p.

Parrotta, J. A. 1989. The influence of management practices on biogeochemical stability of tropical fuelwood plantations. *Tropical Ecol.*, 30: 1-22.

Patel, I. S. and Dodia, D. A. 1999. *Xylodectus ornatus* Linn. (Bostrychidae: Coleoptera) - a wood boring beetle of *Acacia tortilis* in Gujarat. *Insect Environ.*, 4: 123.

Pathak, P. S., Chaube, B. K. and Khan, T. A. 1992. Wood production of *Albizia lebbek* (L.) Benth. from a silvipastoral system. *Range Mgmt. and Agroforestry*, 13: 183-190.

Pathak, P. S. and Gupta, S. K. 1987. The soil ameliorative role of *Leucaena* in agroforestry systems. *In: Agroforestry for Rural Needs Vol. II.* (eds D. K. Khurana and P. K. Khosla). ISTS, Solan: 557-565.

Pathak, P. S. and Rai, P. 1990. Production efficiency of three principal grasses in pure and mixed swards. *Intl. J. Eco. & Environ. Sci.*, 16: 169-178.

Pathak, P. S. and Roy, M. M. 1994. *Silvipastoral System of Production.* A Technical Bulletin. IGFRI, Jhansi: 55 p.

Pathak, P. S., Gupta, S. K. and Singh, P. 1995. *Rehabilitation of Degraded Lands.* IGFRI, Jhansi: 23p.

Pathak, P. S., Khan, T. A. and Deb Roy, R. 1988. Biomass prediction in trees on rangeland. *Abstract (Volume 1) Third International Rangeland Congress* (eds P. Singh, V. Shanker and A.K. Srivastava). RMSI, Jhansi: 147-148.

Patil, F. B., Kunjir, N. T. and Kasole, K. E. 1994. Root studies in agroforestry tree species. *Range Mgmt. and Agroforestry*, 15: 211-215.

Paulsamy, S., Sayeenagavadivel, S. and Manian, S. 1992. Decomposition of forest litter in two different habitates. *In: Silvipastoral Systems in India* (eds P. S. Pathak and P. Singh). RMSI, Jhansi: 127-130.

Pearson, G. A. 1930. Light and moisture in forestry. *Ecology*, 11: 139-144.

Piper, C. S. 1966. Soil and Plant Analysis. *Indian Reprint.* Hans Publications, Bombay, 368p.

Pomeroy, L. S. 1970. The strategy of mineral cycling. *Ann. Rev. Ecol. Syst.*, 1: 171-191.

Prajapati, M. C., Verma, B., Mittal, S. P., Nambiar, K. T. N. and Thippannavar, B. S. 1971. Effect of lateral development of *Prosopis juliflora* DC roots and agricultural crops. *Ann. Arid Zone*, 8: 36-38.

Prasad, R. 1990. Strategy for optimization of grass production from man made forest. *In: Silvipastoral Systems in India* (eds P. S. Pathak and P. Singh). RMSI, Jhansi: 153-157.

Prasad, R. and Misra, G. P. 1985. Litter productivity of dry deciduous forest stand of Sagar (Madhya Pradesh). *Indian For.*, 111: 359-367.

Princely, R. T. and Swift, M. J. (eds) 1986. *Soil Amelioration by Trees.* Commonwealth Science Council, London: 245 p.

Puri, G. S. 1953. Litter fall in Dehra Dun forest. *Bull. Bot. Soc. Univ. Saugar,* 9: 28-34.

Raghuvanshi, A. S., Srivastava, S. C., Singh, R. S. and Singh, J. S. 1990. Nutrient release in leaf litter. *Nature*, 346: 227.

Raheja, P. C. 1966. Rajasthan desert can bloom with forage. *Indian Farming*, 5: 47 p.

Rai, M. P., Pathak, P. S. and Deb Roy, R. 1983. Biomass production of *Sesbania grandifolia* in different habitats. *Intl. J. Ecol. Environment Sci.*, 9: 21-27.

Raizada, A. and Padmaiah, M. 1993. Comparative biomass accumulation in four tree species in an energy plantation: Effect of spacing. *Range Mgmt. & Agroforestry,* 14: 61-66.

Raizada, A. and Rama Mohan Rao, M. S. 1994. Biomass production and its distribution in an age series of *Eucalyptus hybrid* plantation on a red soil watershed. *In: Agroforestry Systems for Degraded Lands* (eds P. Singh, P. S. Pathak and M. M. Roy). Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi: 329-338.

Rajvanshi, R. and Gupta, S. R. 1980. Decomposition of litter in a tropical dry deciduous forest. *Intl. J. Ecol. & Environ. Sci.*, 6: 37-49.

Rajvanshi, R. and Gupta, S. R. 1985. Biomass productivity and litter fall in a tropical *Dalbergia siossoo* Roxb. Forest. *J. Tree Sci.*, 4: 73-78.

Ram Prakash and Drake Hocking (eds) 1986. *Some Favourate Trees for Fuel & Fodder.* Society for Promotion of Wasteland Development, New Delhi: 187 p.

Ramakrishna, Y. S. 1984. Forest microclimate and its importance in agroforestry. *In: Agroforestry in Arid and Semi-Arid Zones* (ed K. A. Shankarnarayan). CAZRI, Jodhpur: 9-14.

Ramakrishna, Y. S. and Sastri, A. S. R. A. S. 1977. Climatological studies on rainfall interception and diurnal variation in the total and net radiant energy available under *Acacia tortilis* trees. *Annual Report.* CAZRI, Jodhpur: 69.

Ramakrishna, Y. S., Sastri, A. S. R. A. S. and Muthana, K. D. 1981. A note on the importance of radient energy penetration in silvopastoral systems. *My Forest*, 17: 1-3.

Reifsnyder, W. E. 1989. Control of solar radiation in agroforestry practice. *In: Meteorology and Agroforestry* (eds W. S. Reifsnyder and T. O. Darnhofer). ICRAF, Nairobi (Kenya): 141-156.

Rosenberg, N. J. 1986. *A Primer on Climate Change: Mechanism, Trends and Prospects.* Discussion Paper Series. RR 86-04. Resources for the Future, Washington DC.

Rosenberg, N. T., Blad, B. L. and Verma, D. B. 1983. *Microclimate: The Biological Environment* 3rd ed., Wiley & Sons, New York, USA.

Roy, M. M. 1991. Some tropical fodder trees for sustained fodder and firewood availability during lean period. *J. Trop. For.*, 7: 196-205.

Roy, M. M. 1992. Lopping management of fodder trees. *In: Status of Indian Forestry - Problems and Perspectives* (ed. P. K. Khosla). ISTS, Solan: 235-242.

Roy, M. M. 1995. Productivity of *Hardwickia binata* Roxb. based silvipastures in Bundelkhand region. *Ph. D. Thesis*. Bundelkhand University, Jhansi: 188 p.

Roy, M. M. and Deb Roy, R. 1983. Lopping studies on *Bauhinea purpurea*. *Myforest*, 19: 193-196.

Roy, M. M. and Deb Roy, R. 1986. Production potential and management of some tropical fodder trees in wasteland development programme. *Nat. Sem. Fuel and Fodder Production under Wasteland*, May, 30-31. FRI, Dehra Dun.

Roy, M. M. and Pathak, P. S. 1990. A guide to seed collection of some tropical fodder trees. *My Forest*, 26: 63-69.

Roy, M. M., Pathak, P. S. and R. Deb Roy 1984. *Dichrostachys cinerea* (L.) Wight & Arn with special reference to its potential on wastelands. *Myforest*, 20: 213-224.

Sahoo, G. B. 1996. Silvipasture System of Forage Production. *Term paper for partial fulfilment of the requirement of national diploma on forage production and its utilization*, IGFRI, Jhansi: 29 p.

Sanchez, P. A. 1987. Soil productivity and sustainability in agroforestry. *In: Agroforestry: A Decade of Development* (eds H. A. Steppler and P. K. R. Nair). ICRAF, Nairobi (Kenya): 205-223.

Sanchez, P. A., Palm, C. A., Davey, C. B., Szott, L. T. and Russell, C. E. 1985. Tree crops as soil improvers in humid tropics. *In: Attributes of Trees as Crop Plants* (eds M. G. R. Cannell and J. E. Jackson). Institute of Terristrial Ecology, National Environmental Research Council, Abbots Ripton, Huntingdon, England: 327-350.

Saxena, A. K., Pandey, U. and Singh, J. S. 1978. On the ecology of oak forests in Nainital hills, Kumaun Himalaya. *In: Glimpses of Ecology* (eds J. S. Singh and B. Gopal). International Scientific Publishers, Jaipur: 167-180.

Seasted, T. R. and Crossley, D. A. Jr. 1981. Microarthopod response following cable logging and clear cutting in southern Applachians. *Ecology* 62: 126-135.

Shankar, V. 1988. Silvipasture research in India. *In: Pasture and Forage Crop Research-A state of knowledge report* (ed. P. Singh) RMSI, Jhansi: 291-304.

Shankar, V. and Gupta, J. N. 1993. Restoration of Degraded Rangelands. *In: Restoration of Degraded Land: Concepts and Strategies* (ed. J. S. Singh). Rastogi Publications, Meerut: 115-156.

Shankarnarayan, K. A., Dabadghao, P. M., Upadhya, V. S. and Rai, P. 1975. Note on NPK effects on *Sehima* grassland. *Indian J. Agric. Sci.*, 45: 383-384.

Shankarnarayan, K. A., Dabadghao, P. M., Upadhya, V. S. and Rai, P. 1976. Effect of fertilizers (N & P) on the aboveground productivity in *Heteropogon*, *Iseilema* and *Sehima* communities. *Tropical Ecology*, 18: 110-112.

Sharma, D. C., Taneja, P. L. and Bist, A. P. S. 1988. Biomass productivity and nutrient cycling in a *Dalbergia sissoo* plantation. *Indian For.*, 114: 261-268.

Sharma, S. K., Dutta, B. K. and Tiwari, J. C. 1996. *Prosopis cineraria* (L.) Druce in silvipastoral system of arid region of western Rajasthan. *J. Range Mgmt. & Agroforestry*, 17: 81-85.

Sheda, M. D. 1992. Forest Cover in India: Present Status and Future Trend. *In: Status of Indian Forestry Problems and Perspectives*. (ed. P. K. Khosla). Indian Society of Tree Scientist (ISTS), Solan: 27-32.

Shukla, R. P. and Ramakrishnan, P. S. 1982. Phenology of trees in sub-tropical humid forest in north eastern India. *Vegetatio*, 49: 103-109.

Singh, A. K. and Ambasht, R. S. 1980. Production and decomposition rate of litter in a teak (*Tectona grandis*) plantation at Varanasi (India). *Rev. Ecol. Biol. Sci.*, 17: 13-22.

Singh, A. K. and Gupta, B. N. 1993. Biomass production and nutrient distribution in some important tree species on *bhata* soils of Raipur (Madhya Pradesh), India. *Ann. For.*, 1: 47-53.

Singh, A. K., Ambasht, R. S. and Mishra, K. N. 1980. Litter production and turnover of organic matter in a tropical *Zizyphus jujuba* shrub community. *Jap. J. Ecol.*, 30: 203-209.

Singh, B. 1988. Biomass potential of some firewood shrubs of north India. *Biomass*, 16:199-203.

Singh, B. 1994. Biomass and nutrients accumulation in *Cryptomeria japonica* plantations of Darjeeling. *Indian For.*, 120: 689-698.

Singh, B., Mathur, H. N. and Joshie, P. 1980. Effect of shade on grassland production in the moist sub tropical region of North India. *Indian J. Forestry*, 3: 343-345.

Singh, D. and Singh, D. 1994 Agroforestry for sustainable development of degraded lands in Bundelkhand region. *In: Agroforestry Systems for Degraded Lands* (eds P. Singh, P. S. Pathak and M. M. Roy), Oxford & IBH Publishing Co., New Delhi: 397-403.

Singh, J. P. and Puri, D. N. 1975. Economic utilization of ravines for fuel-cum-fodder. *Annual Report*, CSWCRTI, Dehra Dun: 39-40.

Singh, J. S. 1968. Net above ground community productivity in the grasslands at Varanasi. *Proc. Symp. Rec. Adv. In Trop. Ecol. (Part II)*, Varanasi: 631-654.

Singh, J. S. 1993. *Restoration of Degraded Land: Concepts and Strategies.* (ed. J.S. Singh), Rastogi Publications, Merrut: 321 p.

Singh, J. S. and Mishra, R. 1969. Diversity, dominance, stability and net production in the grassland at Varanasi. *Can. J. Bot.*, 47: 245-247.

Singh, J. S. and Yadav, P. S. 1972. Biomass structure and net primary production in the grassland ecosystem at Kurukshetra. *In: Proc. Symp. on Trop. Ecol. with an emphasis on Organic production* (eds P. M. Golley and F. B. Golley). University of Georgia, Athens (USA): 59-74.

Singh, J. S. and Yadav, P. S. 1974. Seasonal variation in composition, plant biomass and net primary productivity of a typical grassland at Kurukshetra. *Ecol. Monogr.*, 44: 351-376.

Singh, J., George, M. and Varghese, G. 1993. Nutrient cycling in moist deciduous forest. litter production and nutrient return. *Indian For.*, 119: 1004-1010.

Singh, K. P. 1968.Litter production and nutrient turnover in deciduous forests of Varanasi. *In: Recent Advances in Tropical Ecology* (eds R. Mishra and B. Gopal). ISTE, Varanasi: 655-665.

Singh, K. P. and Singh, J. S. 1988. Certain structural and functional aspects of dry tropical forest and savanna. *Intl. J. Eco. & Environ. Sci.*, 14: 31-45.

Singh, L. N. 1990. Seasonal variation in dry matter production of certain tropical grasses in sub-montane region of western Himalaya. *Range Mgmt. & Agroforestry*, 11: 29-32.

Singh, M. and Keshwa, G. L. 1993. Effect of litter fall of promising tree species of arid zone on physico-chemical properties of soil. *In: Agroforestry in 2000 AD for the Semi-arid and Arid Tropics* (eds A. S. Gill, R. Deb Roy and A. K. Bisaria). NRCAF, Jhansi: 129 p.

Singh, P. 1988. Agroforestry for wasteland development. *Pasture and forage crop research - A state of knowledge report.* Third International Rangeland Congress, New Delhi: 313-321.

Singh, P. 1988 a. Forage research- present status and future strategy. *In: Pasture and Forage Crop Research* (ed. P. Singh), RMSI, Jhansi: 1-15.

Singh, P. 1988 b. *Indian Rangelands - Status and Improvement.* IGFRI, Jhansi: 40 p.

Singh, P. and Roy, M. M. 1993. Silvipastoral systems for ameliorating productivity of degraded lands in India. *Ann. For.*, 1: 61-73.

Singh, P. and Roy, M. M. 1998. Agroforestry and rangeland development. *In: Fifty Years of Agronomic Research in India* (eds R. L. Yadav, Panjab Singh, Rajendra Prasad and I. P. S. Ahlawat). Indian Society of Agronomy, New Delhi: 221-254.

Singh, P., Pathak, P. S. and Roy, M. M. (eds) 1994. Agroforestry Systems on Degraded Lands - An Introduction. *In: Agroforestry Systems for Sustainable Land Use*, RMSI, IGFRI, Jhansi: 1-10.

Singh, P., Pathak, P. S., Upadhya, V. S. and Gupta, S. K. 1990. *IDRC Silvipasture Operational Research Project.* VIII[th] Annual Report. IGFRI, Jhansi: 40 p.

Singh, P., Pathak, P. S., Upadhya, V. S. and Gupta, S. K. 1992. *IDRC Silvipasture Operational Research Project.* X[th] Annual Report. IGFRI, Jhansi: 51 p.

Singh, P., Pathak, P. S., Upadhya, V. S. and Gupta, S. K. 1993. *IDRC Silvipasture Operational Research Project*. XIth Annual Report. IGFRI, Jhansi: 51 p.

Singh, P., Pathak, P. S., Upadhya, V. S. and Gupta, S. K. 1994. *IDRC Silvipasture Operational Research Project*. XIIth Annual Report. IGFRI, Jhansi: 48 p.

Singh, Pratap and Bhandari, R. S. 1987. Insect pests of *Acacia tortilis* in India. *Indian For.*: 734-743.

Singh, R. and Joshi, M. C. 1986. Distribution and cycling of potassium in soil vegetation component of sand dune herbaceous vegetation around Pilani, Rajasthan (India). *Ann. Arid Zone*, 25: 265-276.

Singh, R. and Verma, R. K. 1986. Changes in floristic composition of herbaceous vegetation under three different forest communities at Summer Hill, Shimla. *Indian J. Ecol.*, 13: 205-210.

Singh, R. L. 1971. *India - A Regional Geography.* National Geographical Society of India, Varanasi.

Singh, R. P., Gupta, M. K. and Mathur, H. N. 1985. Effect of *Pinus roxburghii* plantations on the yield and composition of grasses in temperate region. *Indian For.*, 111: 787-793.

Singh, R. V. 1982. *Fodder Trees of India.* Oxford & IBH Publishing Co., New Delhi: 169-177.

Singh, S. P. (ed.) 1994. *Hand Book of Agroforestry.* Agrotech Publishing Academy. Udaipur: 208 p.

Singh, U. N. and Sengar, R. B. S. 1994. Structure and primary production pattern in age series of *shisham* plantation on degraded lands of Bundelkhand region. *In: Agroforestry Sysrems for Degraded Lands* (eds Panjab Singh, P. S. Pathak and M. M. Roy). Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi: 320-328.

Skerman, P. J. and Riveros, F. 1992. *Tropical Grasses*. FAO, Rome and Scientific Publishers, Jodhpur: 832p.

Smith, C. J., Elston, J. and Bunting, A. H. 1971. The effect of cutting and fertilizer treatment on the yield and botanical composition of chalk turf. *J. Brit. Grass. Soc.*, 26: 213-220.

Srivastava, A. K. 1994. Productivity and economics of some commercially important forest trees. *Indian For.*, 120: 12-29.

Srivastava, J. P. L. 1978. Lopping studies on *Prosopis cineraria. Indian For.*, 4: 269-274.

Subba Rao, B. K., Dabral, B. G. and Pande, S. K. 1972. Litter production in forest plantation of *chir,* teak and *sal* at New Forest, Dehra Dun. *Proc. Symp. Trop. Ecol.*: 235-243.

Sugur, C. V. 1989. Litter production and nutrient cycling of different species under plantation condition. *My forest*, 25: 43-49.

Suresh, K. K. and Vinaya Rai, R. S. 1988. Allelopathic exclusion by understorey by a few multipurpose trees. *Intl. Tree Crops J.*, 5: 143-151.

Swaminathan, M. H. and Ravindran, D. S. 1989. Evalution of tree species for use in dry zone silvipastoral system. *Myforest*, 20: 373-376.

Swift, M. J., Heal, O. W. and Anderson, J. M. 1979. *Decomposition in Terrestrial Ecosystems: Studies in Ecology, Vol. 5*. Blackwell Scientific Publication, Oxford, UK.

Tandon, V. N., Negi, M. S., Sharma, D. C. and Rawat, H. S. 1996. Biomass production and mineral cycling in plantation ecosystems of *Eucalyptus* hybrid in Haryana. 2. Distribution and cycling of nutrients. *Indian For.*, 122: 30-38.

Tewari, D. N. 1994. *A Monograph on* Dalbergia sissoo. International Book Distributers, Dehra Dun: 84-93.

Thompson, L. M. and Troeh, F. R. 1985. *Soils and Soil Fertility*. Tata Mc Graw-Hill Publishing Co. Ltd., New Delhi: 516 p.

*Trapp, E. 1938. Untersuchung uber die Verteilung der Haeeigkeit in eimen Buchenbestand. *Biokl. B.*, 5: 153-158.

Trivedi, B. K. and Gupta J. N. 1994. Impact of certain management practices on the vigour of range grasses. *In: Agroforestry Systems for Degraded Lands (Vol. 2)* (eds P. Singh, P. S. Pathak and M. M. Roy). Oxford & IBH Publishing Co., New Delhi: 625-631.

Troup, R. S. 1921 (reprint 1986). *The Silviculture of Indian Trees (Vol. II)*. International Book Distributers, Dehra Dun: 340-361.

Turbull, J. 1984. Tree seed supply : a critical factor for the success of agroforestry projects. *In: Multipurpose Tree Germplasm* (eds J. Burley and P. Von Carlowitz), ICRAF, Nairobi (Kenya).

Tyagi, R. K. 1988. Grazing lands of Bundelkhand - Their present status and future strategies for improvement. *Indian J. Range Mgmt.*, 9: 9-13.

Tyagi, R. K. 1997. *Grassland and Fodder Atlas of Bundelkhand*, IGFRI, Jhansi: 178p.

UNESCO 1979. *Tropical Grazingland Ecosystems- A State of Art Report*, United Nation Educational, Scientific and Cultural Organization, Paris: 655p.

Vadiraj, B. A. 1993. The influence of *Casuarina* age on soil characteristics in Karnataka, *J. Trop. For.*, 9: 55-62.

Van den Beldt, R. J. 1983. Effect of spacing on growth of *Leucaena. In: Leucaena Research in the Asia-Pacific Region*, IDRC, Ottawa, Canada.

Varshney, U. K. and Garg, A. K. 1996. Litter production pattern in *Albizia lebbek* plantation stand at Hisar. *Indian For.*, 122: 813-816.

Verma, S. C. and Misra, P. N. 1986. Biomass and energy production in coppice stands of *Sesbania Sesben* (Linn.) Merrill under high density plantation on marginal lands of Banthra. *Biomass*, 11: 309-313.

Verma, S. C. and Rao, M. V. 1988. Production potential of grassland ecosystem on marginal lands of Banthra. *Indian J. Range Mgmt.*, 9: 37-47.

Virginia, R. R. and Jarrel, W. M. 1983. Soil properties in a mesquite dominated sonoran desert ecosystem. *Soil Sci. Soc. Am. J.*, 47: 138- 144.

Vitousek, P. M. 1984. Litter fall, nutrient cycling and nutrient limitations in tropical forest. *Ecology*, 65: 285-298.

Vitousek, P. M. and Matson, P. A. 1985. Disturbance, nitrogen availability and nitrogen losses in an intensively managed loblolly pine plantation. *Ecology*, 66: 1360-1376.

Vogt, K. A., Grier, C. C. and Vogt, D. J. 1986. Production, turnover and nutrient dynamics of above and below ground detritus of world forests. *Adv. Ecol. Res.*, 15: 303-377.

Wang, D., Bormann, F. H., Lugo, A. E. and Bowden, R. D. 1991. Comparision of nutrient use efficiency and biomass production in five tropical tree taxa. *Forest Ecol. & Mgmt.*, 46: 1-21.

Weaver, J. E. and Clements, F. E. 1938 (reprint 1986). *Plant Ecology.* Tata Mc Graw-Hill Publishing Co. Ltd., New Delhi: 356-379.

White, E. M. 1971. Grass cycling of calcium, magnesium, potassium and sodium in solodization. *Soil Sci. Soc. Am. Proc.*, 35: 209-211.

White, E. M. 1973. Water leachable nutrients from frozen or dried praire vegetation. *J. Environ. Qual.*, 2: 104-107.

Whittaker, R. H. and Likens, G. E. 1975. *The Biosphere and Man (Ecological Studies Vol. 14)* (eds H. Leith and R. H. Whittaker). Springer-Verleg, New York.

Wilken, G. C. 1972. Microclimate management by traditional farmers. *Geographical Review*, 62: 544-566.

Willey, R. W. 1975. The use of shade in coffee, cocoa and tea. *Horticultural Abstracts*, 45: 791-798.

Yadav, J. S. P. and Singh, K. 1970. Tolerance of certain forest species to varying degree of salinity and alkalinity. *Indian For.*, 96: 587-599.

Young, A. 1991. Soil Fertility. *In: Biophysical Researh for Asian Agroforestry* (eds M. E. Avery, M. G. R. Cannell and C. Ong). Winrock International, USA: 187-207.

* Original not seen